1954

Comparison of leguminous green manures with inorganic nitrogen in rotations with corn

Henry August Fribourg
Iowa State College

COMPARISON OF LEGUMINOUS GREEN MANURES
WITH INORGANIC NITROGEN IN ROTATIONS WITH CORN

by

Henry August Fribourg

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
DOCTOR OF PHILOSOPHY

Major Subject: Agronomy: Crop Production and Soil Management

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

Head of Major Department

Signature was redacted for privacy.

Dean of Graduate College

Iowa State College

1954

TABLE OF CONTENTS

I. INTRODUCTION

The north-central area of the United States is particularly well adapted to the culture of corn (Zea mays). Of the eighty million acres of corn harvested in the United States in 1952 (85), one-eighth was located in the state of Iowa. The mean yield of corn in the United States is approximately 40 bushels per acre, which is considerably lower than the mean yield in Iowa.

Since Corn Belt farmers in general, and most Iowa agricultural producers in particular, rely to a large extent upon corn as a direct or indirect source of revenue, economic increases in production per acre within the framework of sound agricultural management are of paramount importance to them. Within the last decade and a half, the increasingly wide-spread acceptance of mechanization, liming, commercial fertilizers, soil-erosion control methods, improved genetic strains of crop plants and many other practices resulting in higher yields, has brought attention to the limiting aspects of nitrogen in crop production.

Increased realization of the need for nitrogen and the decrease in price of this fertilizing element associated with industrial progress and expansion both have brought about a very large increase in the use of nitrogenous fertilizers. While only a few hundred tons of nitrogen fertilizer were used annually in Iowa until the end of the second World War, the 1950 consumption exceeded 20,000 tons. In 1951, almost 30,000 tons of nitrogen fertilizer were sold in Iowa, and indications are the consumption may increase much more.

In addition to animal manure and inorganic fertilizer, another large potential source of nitrogen can be tapped in the form of the Leguminosae. Appreciation of the value of legumes goes back to antiquity. Since the advent of scientific agriculture, legumes have been used to an even greater extent than previously. In some instances, these plants have been used singly or in combination with grasses for forage purposes; in other cases, they have been plowed under as green manures. Usually, legumes established for forage have been maintained for at least one season and oftentimes longer. When growing such a crop for green manure, however, the legume should not interfere with normal agricultural sequence of crops.

For a number of years, biennial and annual sweetclovers (Melilotus spp.) have been commonly grown in the Corn Belt for green manure purposes. In the last few years, however, attacks of sweetclover weevil (Sitona cylindricollis) have necessitated the additional expense of control sprays. Simultaneously, surpluses of southern-grown common alfalfa (Medicago sativa) and ladino clover (Trifolium repens) have reduced seed costs of these legumes and made possible their use for purposes other than forage crop production.

This investigation was initiated, therefore, to compare these and other legumes for nitrogen production, and to evaluate their gross effects on a succeeding corn crop in comparison with ammonium nitrate fertilizer. In the main, six legumes were studied: Madrid, a variety of yellow-flowered biennial sweetclover (Melilotus officinalis), Hubam, a variety of white-flowered annual sweetclover (*Melilotus alba*), Grimm and southern-grown common alfalfas, medium red clover (*Trifolium pratense*) and ladino clover.

In the evaluation of these legumes, quantitative growth characteristics of aerial and subterranean portions of the plants were investigated, particularly as regards yield and nitrogen content. Additional experiments were conducted to compare availability to corn of nitrogen from freshly-cut and other organic materials. Exploratory studies also were carried out with a relatively large number of other legumes with varying degrees of adaptation to Iowa, for the purpose of estimating their potential value as green manures.

II. REVIEW OF LITERATURE

Green manuring, or the plowing under of green plant materials for soil improvement, is a very old agricultural practice. Historical records reveal that this practice was followed by Chinese over three thousand years ago, and it is a well-known fact that Greek and Roman writers expounded the value of alfalfa (medic), lupines and other legumes for soil improvement (61, 65, 95). It was not, however, until the nineteenth century that the studies and experiments of Boussingault, Liebig, Ville and later, Lawes and Gilbert at Rothamsted, led to a gradually better understanding of the nature of the soil-improving quality of legumes. The key to the puzzle was finally attained by Hellriegel and Wilfarth in 1887 (101). Detailed historical treatises with respect to this topic have been written by O'Grady (61), Pieters (65) and Wilson (101).

Under specific environmental conditions, not only legumes, but also non-nitrogen fixing plants have been used for soil improvement. Many grasses, in particular, have been utilized for covering and protecting soil surfaces from erosion or other unfavorable conditions, and to minimize leaching effects. In this review, however, the use of legumes is primarily of interest and, furthermore, only of those legumes adapted to climatic conditions similar to those of the Corn Belt.

In view of the length of time that has expired since the value of legumes was recognized, and also in view of the wide acceptance that these plants have received for forage and green manuring purposes, it is surprising that there is a great dearth of critical evaluation of leguminous green manures. A survey of the world literature revealed a scarcity of information of a critical nature where both the total amount of growth or total nitrogen in the legume and also the response of succeeding crops to the green manure had been evaluated. The present literature review will deal with two major phases of the problem: yields of dry matter and nitrogen in the roots and tops of legumes, and response obtained from their use as measured in the succeeding crop.

Critical evaluation of the value of a leguminous green manure requires not only an estimate of its effect on a succeeding crop, but also an estimate of total yield of both roots and tops with respect to dry matter and particularly nitrogen. The great majority of the literature on legume root yields concerns itself primarily with sweetclover and alfalfa. In many cases, these plants were studied in the course of investigations on cutting and other management practices, rather than directly in a green manure study.

Whiting and Richmond (91) say that Orth, in 1890, was the first scientist to test green sweetclover in comparison with manure for the production of potatoes (Solanum spp.); although he did not measure the actual yield of sweetclover, he did conclude that, under his conditions, sweetclover was as good as or better than manure. Arny and Thatcher (3) reported in 1915 the production of 110 to 120 pounds of nitrogen by either alfalfa or sweetclover in the second year of growth. Biennial yellow or white sweetclovers yielded one and a quarter tons of dry matter in Minnesota, and 500 pounds more than annual white sweetclover, producing from 30 to 60 pounds of nitrogen per acre (2). The tops were higher in nitrogen content than the roots, and the authors also stated that root yields determined by means of two square-yard quadrats were more variable than top yields. In this connection, Goedewaagen and Schuurman (30, 31) pointed out that the kind of crop, the environmental conditions (especially edaphic) and the methods of sampling and separating roots from soil have resulted in great variation in amounts of roots and stubble reported by different investigators. They also observed that root yields, as reported in literature from 1860 to 1950, showed a decreasing variation with time, probably as a result of development of better techniques. The authors concluded the best estimate of root production of any one crop would be obtained by averaging the values obtained by different investigators. They reported, at least for northwest European conditions, yields of 57, 22 and 14 quintals per hectare of roots (down to 20 cm. depth) and stubble, for alfalfa, red and white clovers, respectively.

Snider and Hein first reported in 1926 (76) and then again in 1934 (77) the results of numerous samplings of sweetclover tops and roots in the fall of the seeding year and the following spring. In the first report, four tons dry matter of roots and tops were produced, containing over 200 pounds of nitrogen. The latter study, conducted also in Illinois, reported total yields of almost 150 pounds of nitrogen, of which one-fifth was in the roots. Top-root ratios were found to decrease from summer to late fall of the seeding year, and increase again over winter.

In 1927, Willard published his classical bulletin on yields and nitrogen content of sweetclover grown in Ohio (98), compared under similar conditions to alfalfa and red clover. In the fall of the seeding year, white biennial sweetclover had produced over a ton of dry matter each in tops and roots. Yellow sweetclover produced slightly less in the tops, but the root yields were of the same magnitude. Alfalfa, on the other hand, yielded 1700 pounds in the tops and 1400 in the roots, while red clover produced one ton dry weight in the tops and a quarter ton of roots. Hubam sweetclover produced as much as two tons dry matter in the tops, but the root system contributed only 360 pounds per acre. The nitrogen content of the various legumes did not differ markedly, but the total yields of nitrogen were quite different. The biennial sweetclovers yielded a total of 110 to 140 pounds of nitrogen per acre, as compared to 84 for Hubam, 78 for alfalfa and 69 for red clover.

Badger and Snider (5) indicated that sweetclover seeded in late winter yielded only 2500 pounds dry matter (81 pounds of nitrogen per acre) fourteen months after planting in Illinois. In general, however, reported yields of sweetclover from six to eight months after seeding are higher than these values. Wilkins and Collins (96), working in Iowa, reported in 1933 fall yields of a ton and a half of dry matter containing over 100 pounds of nitrogen. In western Minnesota, October yields of over two and a half tons of dry matter were obtained for both biennial yellow and biennial white sweetclovers when seeded alone (23). Under these conditions, however, the presence of an oat (Avena sativa) companion crop reduced yields drastically.

Burnett (14) in Iowa and Hawk (36) in Washington both studied different species of biennial sweetclovers in 1938. Fall yields of most of these sweetclovers were of the magnitude of two tons of dry matter per acre, divided approximately equally between tops and roots. The nitrogen content of roots was usually higher than that of tops, ranging between 2.5 and 3.1 percent nitrogen. The nitrogen production ranged from over 100 to 60 pounds per acre.

When grown on heavy soils in Michigan (17), alfalfa and sweetclover did not yield as high as under other conditions. Even though the yields were obtained in the spring following seeding, sweetclover produced only 1400 pounds dry matter in the tops and 1100 pounds in the roots, equivalent to 50 and 31 pounds of nitrogen per acre, respectively. Davis and Turk (19) under similar conditions, reported over two and a half tons dry matter and 129 pounds of nitrogen from alfalfa, but only one ton dry matter and 60 to 90 pounds of nitrogen for sweetclover. The authors indicated that an increase in the yield of sweetclover tops was associated with a decrease in root yields. A similar relationship also appeared to occur with respect to nitrogen and other mineral elements.

Lamba et al. (45), in a study of root growth of alfalfa, red clover and other forages in Wisconsin, obtained varying results due to location effects. At two experimental sites, yields of alfalfa roots approached two and a half tons dry matter per acre; at the other two, approximately one and a quarter tons were obtained in the fall of the seeding year. Red clover root yields were inferior to those of alfalfa, ranging between three quarters to one and a half tons of dry matter. The authors further indicated that the major part of the roots was in the top eight inches, and that the next eight inches accounted for most of the remainder.

More recently, Butijn (15) reported September dry matter yields of legumes seeded in the second half of April in the Netherlands. Alfalfa yielded over 4300 kilograms per hectare of tops, and 1200 kilograms of roots; red clover, 5800 and 1100; white clover, 4100 and 1300; hairy vetch (_Vicia villosa_), 5920 and 80; and sub clover (_T. subterraneum_) yielded 15,550 kilograms of tops and 300 kilograms of roots per hectare. These yields are considerably higher, under the moist Dutch climate, than many of those reported under American conditions. At the other extreme, Evergreen sweetclover grown in Texas, on Houston black clay (39), yielded almost one ton dry matter per acre of tops, and three-quarters of a ton of roots when unfertilized; addition of phosphorus substantially increased dry matter yields of both tops and roots. The nitrogen yields obtained from this sweetclover ranged from 35 to 40 pounds in tops and roots to as high as 55 pounds in the roots and 117 pounds in the tops when band-fertilized with phosphorus.

Summaries of data obtained over a period of years in Ohio have been published (62). Yields of dry matter and nitrogen in the fall of the seeding year were presented for alfalfa, red clover and sweetclover, as well as the seasonal development of these yields for sweetclover. Compared to 1550 to 2280 pounds dry matter per acre in sweetclover tops, alfalfa tops yielded approximately 1500 pounds and red clover tops around 2200 pounds per acre. Sweetclover root yields ranged between 1700 and 2700 pounds per acre, while alfalfa roots yielded 1100 pounds and red clover roots between 500 and 900 pounds dry matter per acre. There was little difference between nitrogen content of roots and tops of red clover or alfalfa, but sweetclover roots were much higher than sweetclover tops in nitrogen percentage. Sweetclover yielded between 120 and 130 pounds of nitrogen in tops plus roots, whereas red clover and alfalfa contained around 75 pounds of nitrogen in the fall of the seeding year. Detailed studies of sweetclover development indicated that three quarters of the total nitrogen had been accumulated by September 15, and 100 pounds of nitrogen per acre had been produced by October 15.

Recent work in Minnesota (6) compared the top and root yields of red clover, biennial white and Hubam sweetclovers and alfalfa, as affected by fertilizer applications. The yield estimates were made in the fall of the seeding year, and the roots were sampled to a depth of six inches. Data for one year at two locations indicated that both sweetclovers yielded a total of about 1700 pounds dry matter per acre. However, Hubam contained only 300 pounds in the roots, while almost two thirds of the total yield of biennial white sweetclover was underground. Red clover and alfalfa yields were equally divided between tops and roots, the former yielding a total of 1200 pounds per acre, and the latter a half ton.

Summary of a number of experiments at diverse locations over several years by Snider (75) for alfalfa and sweetclover grown in Illinois substantiated to a large extent the information previously presented. Fall yields in the seeding year approximated a ton or more of dry matter per acre (up to two tons in some cases) for both legumes. Alfalfa tops yielded more than alfalfa roots, and the reverse was the case for sweetclover. Total nitrogen production varied from 80 to over 100 pounds for alfalfa, and from 130 to 170 pounds per acre for sweetclover.

The distribution of nitrogen in the legume plants has been studied by some investigators under field and/or greenhouse conditions to a greater degree of refinement than afforded by a separation only into roots and tops. Whiting and Richmond (92) sampled 12-months old biennial white sweetclover to a depth of 14 inches, and separated the leaves from the stems. The tops yielded 2600 pounds dry matter per acre, containing 109 pounds of nitrogen, and the roots yielded 111 pounds of nitrogen from 3100 pounds dry matter. Of the total nitrogen yield of 220 pounds, 60 percent were in the roots, 24 percent in the stems and the remaining 16 percent in the leaves. Sampling in the fall of the seeding year in Ohio, Smith (74) found that leaves of yellow sweetclover contained 4.33 percent nitrogen, stems 1.73 percent and roots 3.10 percent, as compared to 4.50 percent, 1.50 percent and 3.42 percent, respectively, for biennial white sweetclover.

Little information was encountered in the literature with respect to top and root yields of other legumes of possible green manure value for use in the Corn Belt. Though some of these species, such as vetch or lespedeza (<u>Lespedeza</u> spp.) have been grown extensively in some parts of the United States, quantitative data on their growth habits has been, for the most part, restricted to crops grown under environmental conditions very different from those in Iowa. Ward (89) obtained yields of five tons dry matter in the tops and one and a half tons in the roots of sericea lespedeza (*L. cuneata*) in southeastern Iowa. In the same experiment, birdsfoot trefoil (*Lotus corniculatus*) yielded two tons dry matter in the tops and one and a half tons in the roots. However, these two species were over one year old at the time of sampling. Rogers and Sturkie (67) noted that hairy vetch grown in Alabama from September to April yielded 2400 pounds dry matter per acre, of which 80 to 85 percent were in the tops. Furthermore, the tops were higher in nitrogen content than the roots; only ten percent of the total nitrogen yield of 75 pounds per acre was in the roots.

Though partridge pea (*Chamaecrista fasciculata*) has been extensively studied by workers in India and the Far East, information as to its yields in the United States is limited. In the southeastern states, yields of green material (tops) of over five tons per acre have been obtained from stands seeded with as little as ten pounds per acre (4). Goodding et al. (32), describing this legume and its use and adaptation, mentioned that partridge pea hay was as high as lespedeza hay in crude protein content, but lower than alfalfa, sweetclover or vetch, and that it was considerably higher than any other legume studied in crude fiber content. Bozovaisky (9) concluded in 1936 that good stands of woods clover (*Dalea alopecuroides*) were obtained only after fungicidal treatment of the seed, and that this legume made better growth than sweetclover on acid soils.

Summarizing, it can be said, in accordance with the statements of Goedewaagen and Schuurman (31) and many others, that reported total yields of dry matter, including roots, are variable because of many factors, outstanding among which are kind of crop, environmental conditions and sampling techniques. Any attempt to characterize a particular crop with respect to both top and root production must take into account climatic and edaphic factors, and allow for distinct yield estimation procedures. Some investigators have harvested roots to a great depth (19, 76) while others have gone down to one-foot depth (2, 74) or less (92, 96). Some have harvested two (77, 98), three (36) or more (96) quadrats of varying sizes and shapes. Still other investigators have sampled roots on the basis of representative plants per se (92, 71) rather than on a unit area basis. However, some of these differences in technique may not be important (30). Most roots of one-year old or younger leguminous plants probably occur in the top foot of soil (45) and even heavy soils may not promote root systems as branched as some investigators have maintained (16). Upchurch and Lovvorn (84) presented data in 1951 indicating that alfalfa in North Carolina did not produce much more branch roots on clayey than on sandy soils. They also found, with only one exception, that over half of the laterals occurred within the top three inches of the soil.

When grown under normal conditions in their proper areas of adaptation, sweetclovers, alfalfa and the more widely used clovers appeared to yield over one ton and less than three tons of dry matter per acre in tops and roots sampled in the fall of the seeding year. Sweetclovers in many instances have yielded as much as a ton of dry matter each in roots and tops. Alfalfa usually yielded less than sweetclover, but often produced as much as a ton and a half or more of dry matter. Red and white clovers in most cases were inferior in fall growth to alfalfa. Vetch and Hubam sweetclover produced very high yields of tops, but low root yields. In general, biennial species yielded more than annuals; longer-lived plants tended to produce heavier root yields when compared to their top yields than did annuals.

Biennial sweetclover yielded as much as 150 to 160 pounds of nitrogen in tops and roots of the first year's growth. Most data, however, indicated production of 100 to 130 pounds of nitrogen. Alfalfa nitrogen yields were somewhat smaller, ranging between as low as 50 pounds to over 100 pounds per acre in some cases. Other legumes, when grown under favorable conditions, and when thick stands were obtained, usually yielded from 50 to 80 pounds of nitrogen per acre.

Since growing a leguminous green manure, within the scope of this study, was primarily for the purpose of increasing yield of the succeeding crop, not only are the nitrogen yields of legumes of interest, but also the yield increases in succeeding crops. It is difficult to evaluate the effect of a particular green manure in investigations where only the responses of other crops have been presented, to the exclusion of legume data. Most of the data from crop rotation studies compare a green manure or catch crop with some other forms of rotational management and do not include data on total growth and quantitative characteristics of the legume.

In 1890, Schloesing reported work done by Muntz (54) which indicated yields of 78,000 kilograms of maize per hectare following alfalfa green manure, as compared to 39,500 kilograms with no alfalfa treatment. Muntz also indicated that addition of alfalfa or inorganic nitrogen to soil resulted in eight to twelve times greater nitrate release than no treatment. Maynard (51) reviewed the American literature on sweetclover published as of 1917, and stated that he found no record of any study on sweetclover green manure decomposition. Pieters (64) concluded, in the same year, that the evidence indicated that leguminous crops increased yields of the following crop on the eastern seaboard, and that red clover was a good green manure for the northern sections of that area. He also commented that there still existed need for evidence to determine if a non-legume was as good as a legume green manure, and questionned whether the effects of green manures were due to the plants per se, or to rotation effect. Even to date, this paramount issue is far from resolved.

Wilkins et al. (97) reported in 1931 the results of work done in Iowa over a five-year period. Yields of corn after fall plowing under of medium red clover and Hubam sweetclover were compared with spring plowing under of biennial white sweetclover. They found that in general biennial sweetclover resulted in yield increases of approximately 20 percent. In two out of five years, Hubam sweetclover resulted in similar responses, but corn responded to red clover green manure in only one year.

Increased yields of from 8.9 to 17.2 bushels of corn were obtained on Brookston clay loam by Davis (17) following spring plowing under of a ton and a half of sweetclover dry matter containing 76 pounds of nitrogen in the tops and roots. Obenshain and Gish (60), working in Virginia, obtained somewhat higher responses to different leguminous green manures, though corn yields in general were lower and crop management different. Eight-year average yields of corn following buckwheat or rye green manure without added nitrogen were 13 and 18 bushels, respectively, while check yields were 20 bushels. Sweetclover green manure seeded at the last corn cultivation the previous year resulted in a seven-bushel increase over check, as compared to 13 to 14 bushels increase following annual applications of either 100 pounds per acre of sodium nitrate, or vetch, red clover or crimson clover (T. incarnatum) green manure.

Results were recently reported (62) on a large number of rotation and green manure studies carried out in Ohio. On Wooster soil, sweetclover in a two-year rotation with corn compared favorably with 80 to 120 pounds per acre of elemental nitrogen applied in the form of ammonium sulfate. Alfalfa was equal to sweetclover when the two legumes were sown in oats and plowed down for corn, whereas corn yields after mammoth red (T. pratense) and medium red clovers were somewhat lower.

Smith (72) reported in 1952 the results of Missouri rotation and other experiments for ten or more years. Sweetclover green manure in a corn-wheat rotation increased yields from 28 to 52 bushels of corn and from 16 to 22 bushels of wheat per acre when compared to the same rotation without sweetclover during the period 1924-1948. These increases were superior to those obtained from the application of eight tons of manure turned under before the corn.

Leguminous green manures seeded in oats in a two-year rotation of corn-oats at several locations in Minnesota were evaluated by Schmid et al. (70). When fertilized with both phosphorus and potassium fertilizers, biennial white sweetclover yielded 1900 pounds of total dry matter per acre, of which 1200 pounds were in the roots. Alfalfa, in the fall of the seeding year, yielded 1200 pounds dry matter equally divided among tops and roots. Medium red clover produced 700 pounds in the tops and 600 in the roots. When corn yield of check was 40 bushels, biennial white and Hubam sweetclovers green manure increased yields by seven bushels, Kansas common alfalfa increased yield by ten bushels and medium red clover resulted in a yield of 53 bushels. The authors pointed out that sweetclover yields were decreased by attacks of sweetclover weevil, and that Hubam sweetclover growth was not very vigorous.

As a result of field, greenhouse and laboratory experiments, Löhnis (47) concluded in 1926 that green manures varied greatly as to the availability of their nitrogen. These variations depended upon quality and quantity of substances used and on soil type. In general, small amounts of young materials gave higher percentage returns than large quantities of older materials. The average availability of nitrogen in green manure was about 50 to 80 percent over a period of years. Löhnis also pointed out that in some cases addition of green manure so intensified mineralization of nitrogen that more nitrogen was recovered in the growing crop than had been incorporated from the green manure.

Whiting (90) noted that sweetclover and alfalfa were superior in nitrification rate to red and alsike clovers. Roots of sweetclover, although of lower nitrogen content than the leaves, nitrified more rapidly than either leaves or stems (93). Whiting and Richmond (94) stated that nitrification of both fall- and spring-plowed sweetclover proceeded rapidly; however, more "active" organic matter was plowed under in spring- than in fall-plowing. Measurement of carbon dioxide evolution, nitrate accumulation and other characteristics indicated that alfalfa roots incorporated in soil decomposed more rapidly than sweetclover roots, and that both these materials decomposed more readily than straw (50). The greatest difference among materials was observed at the beginning of the experiment, the ranges diminishing thereafter. Alfalfa roots and crowns, containing approximately two percent nitrogen, have been found to be decomposed to the extent of 70 percent at the end of four and a half months (20).

Spaulding and Eisenmenger (78) studied the nitrate production in Merrimac sandy loam from addition of equal amounts of alfalfa, red clover, white sweetclover and corn stover to the soil. When the nitrate production of soil to which alfalfa containing 2.43 percent nitrogen had been added was considered to be 100, the addition of red clover or sweetclover containing 1.76 and 1.67 percent nitrogen respectively, resulted in nitrate production of approximately 54. Corn stover treatment resulted in relative nitrate production of only 14. The authors concluded, on the basis of these and other data, that the rate of decomposition of alfalfa was 84 percent of the inorganic control, red clover 42 percent, sweetclover 49 percent and corn stover 22 percent.

Plowing under or discing in first year sweetclover residues prior to corn planting led to high nitrification rates and high available nitrogen content in Nebraska soil (49). Over 60 pounds of nitrate nitrogen were measured in the top foot of soil, and almost 100 pounds per acre in the top three feet. Under dry-land conditions, however, the application of 60 pounds of nitrogen in the form of alfalfa hay did not appreciably increase wheat yield over no treatment over a twenty-two year period in a wheat-fallow system of cropping. When the plots were annually cropped to wheat, the wheat yields increased from 20 to 27 bushels per acre as a result of alfalfa hay applications. Under similar conditions, equivalent amounts of nitrogen in the form of sodium nitrate resulted in average wheat yield of 30 bushels per acre (73).

In summary, the incorporation of organic materials high in nitrogen content usually has increased yields of succeeding crops. However, climatic, edaphic and other factors have resulted in wide variations which were superimposed upon the effects due to kind, amount and stage of growth of the green manures. Although considerable effort has been devoted in the past to the study of the nitrogen cycle, our knowledge of this biological phenomenon is still seriously lacking in a number of respects. Work carried out in the laboratory and the greenhouse has been and is clarifying the situation, but field data with respect to availability of nitrogen from leguminous green manures is still fragmentary and much less complete than the existing information on organic residues of low nitrogen content. General discussions and review of the subject have been presented by Norman (58), Ensminger and Pearson (25) and Broadbent (11).

III. MATERIALS AND METHODS

Three experiments, each with somewhat different objectives, were conducted in Iowa during the period 1951-1953. The procedures used in each set will be presented separately.

A. Green Manure Experiments

These studies were carried out at four locations, i.e., at the experimental farms located at Ames, Clarinda, Kanawha and Marcus. The sites are located in some of the major corn-producing areas of the state, and on soils where a short rotation involving the use of leguminous green manures could conceivably be practicable and valuable.

A two-year rotation was used in the experiment. During the first year, different legumes were grown with an oat companion crop and plowed under in late Fall. In the second year, corn was employed to evaluate the effects of the leguminous green manures. Two rotation cycles were used in the investigation: the first one was started in 1951 and the other was initiated in 1952.

1. Soil types

Wherever possible, the two rotation cycles were contiguous in the same field; such was the case at all locations except Marcus. Even there, however, the soil type was the same in both fields.

At Ames, the experiments were located at the Agronomy Farm. Each year, two of the replications were on Webster silty clay loam and the other two were on a Nicollet loam - Webster silty clay loam intergrade. The Clarinda experiments were located at the Soil Conservation Experimental Farm in southwestern Iowa on Marshall silt loam. The field had approximately a seven percent slope and a western exposure. The Kanawha investigation was conducted at the North Iowa Experimental Association Farm, on a level Nicollet - Webster intergrade.

At Marcus, the experiments were carried out on the John Sand farm on a Marcus silty clay loam or an intergrade between this soil type and Primghar silt loam.

The fertility status of the soils on each experimental site, as determined by the Iowa Soil Testing Laboratory on samples collected in the early spring of 1951, is presented in Table 1.

Table 1. Soil tests for soils at each of four experimental areas in Iowa in the spring of 1951

	Ames	Clarinda	Kanawha	Marcus
pH	6.1	6.1	7.2	6.3
Available P, lbs./A	9.2	5.8	36.8	10.2
Available K, lbs./A	169	374	219	400

2. Experimental design

A randomized complete block design with four replications was used in all cases. A replication consisted of ten plots, arranged in two ranges of five plots each. Each plot measured 13'4" x 23'4", thus accommodating, in the corn year, twenty-eight hills checked forty inches apart. (See Fig. 1)

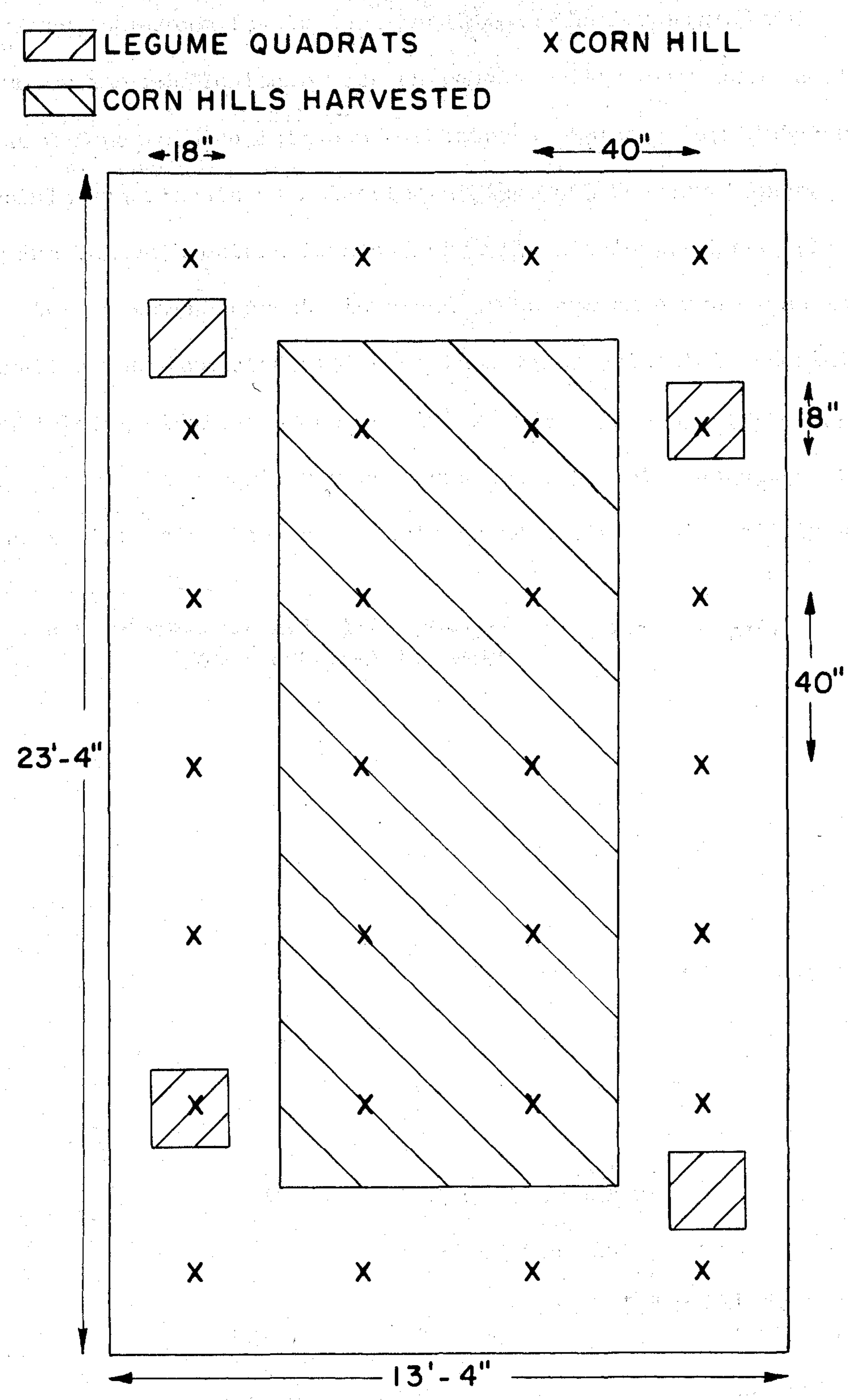
3. General agronomic information

Much of the relevant information concerning dates of planting and harvesting, fertilizer applications, etc. is presented in Table 2. At most locations, a liberal application of phosphorus and potassium fertilizer was broadcast in the spring and disced in prior to seeding or planting, particularly in the corn year. At Marcus in 1953, due to an unfortunate misunderstanding, the corn ground also received a blanket application of thirteen pounds of elemental nitrogen per acre in the form of 13-39-0 fertilizer.

At Ames, Clarinda and Kanawha, the companion crop in the legume seedings was certified Cherokee oats drilled at the rate of six pecks per acre. The Benton oats at Marcus 1951 were drilled at the rate of two bushels per acre, whereas the flax in 1952 at the same location was drilled at the acre rate of three pecks. The legume seedings, mentioned in detail in the succeeding section, after inoculation with the proper strains of Rhizobia, were broadcast on the surface and rolled or harrowed.

In 1951, attempts were made to control sweetclover weevil damage by means of D.D.T. spray and/or dust applied on the seedings from one to two weeks after emergence. This treatment was repeated as many as three or four times at some locations, with varying degrees of success. In 1952, a pre-emergence application of one-half pound of Dieldrin per acre resulted in complete control of the pest.

Fig. 1. Plan of a typical plot showing location and size of harvested areas


LEGUME QUADRATS
X CORN HILL
CORN HILLS HARVESTED
18"
40"
18"
40"
23'-4"
13'-4"

The companion crops in all cases were harvested for grain at maturity during the first half of July. The legumes were allowed to grow until a killing frost occurred in the fall, at which time they were sampled for yield (as described in a subsequent section) and plowed under.

Corn single crosses were used at all locations in an effort to minimize plant to plant genetic variation. In 1952, six kernels were hand-planted in each hill, whereas the following year, eight kernels were dropped. Approximately four weeks after planting, and the same day as the ammonium nitrate side-dressings were applied (as described in the following section), the stands were thinned by hand to an approximate average of four and a half plants per hill. Actual average stands are presented in Table 2.

4. Treatments studied

The ten treatments studied fall in two categories:

a) The first group consisted of six legumes seeded with a companion crop at the rate of seventy viable seeds per square foot. The approximate rates of seeding of these legumes, in pounds per acre, are given below.

Treatments	Approximate seeding rate Pounds per acre
Grimm alfalfa	15
Southern common alfalfa	15
Madrid sweetclover	16
Hubam sweetclover	16
Medium red clover	12
Ladino clover	3.5

Table 2. Fertilizer applications and other information on agronomic procedures at four locations in Iowa, 1951-53

	Ames	Clarinda	Kanawha	Marcus
1951 Legume seedings				
Previous crops	3 years corn	2 years corn	2 years corn	2 years corn
Companion crop	Cherokee oats	Cherokee oats	Cherokee oats	Benton oats
Broadcast fertilizer	200 lbs./A 4-16-8	200 lbs./A 4-16-0	None	200 lbs./A 4-16-8
Date of seeding	May 15	May 5	May 8	May 7
Date of legume yield sampling	September 29	October 13	October 7	October 6
1952 Corn				
Kind planted	WF9 x Hy	WF9 x 38-11	WF9 x M 14	WF9 x B9
Date planted	May 8	May 2	May 14	May 10
Plant population	16,110	16,350	16,560	17,390
Broadcast fertilizer	300 lbs./A 0-20-20	90 lbs./A 0-45-0	300 lbs./A 0-20-20	300 lbs./A 0-20-0
Side-dressed NH_4NO_3				
N_1	59.4 lbs./A	68.4 lbs./A	64.2 lbs./A	67.8 lbs./A
N_2	148.2	147.3	144.3	145.8
N_3	333.0	345.3	294.0	291.6
Date of leaf sampling	July 24	July 15	July 24	July 25
Date of harvest	October 8	October 10	September 28	October 18

Table 2 (continued)

	Ames	Clarinda	Kanawha	Marcus
1952 Legume seedings				
Previous crops	4 years corn	3 years corn	3 years corn	2 years corn
Companion crop	Cherokee oats	Cherokee oats	Cherokee oats	Redwood flax
Broadcast fertilizer	200 lbs./A 4-16-8	90 lbs./A 0-45-0	None	240 lbs./A 0-20-0
Date of seeding	April 8	April 1	April 18	April 12
Date of legume yield sampling	October 4	October 11	September 28	September 27
1953 Corn				
Kind planted	WF9 x B 14	WF9 x B 14	B 8 x B 16	WF9 x B 6
Date planted	May 8	May 13	May 16	May 17
Plant population	18,095	19,520	18,660	20,100
Broadcast fertilizer	400 lbs./A 0-20-35	400 lbs./A 0-20-22	400 lbs./A 0-20-22	400 lbs./A 3.25-120-22
Side-dressed NH_4NO_3				
N_1	77.1 lbs./A	82.2 lbs./A	81.0 lbs./A	80.7 lbs./A
N_2	154.2	164.7	162.0	161.4
N_3	247.8	247.8	239.1	249.9
Date of leaf sampling	July 16	July 14	July 17	July 15
Date of harvest	October 6	October 10	October 18	October 11

b) The second group included the four remaining treatments which were planted with the companion crop but not seeded with legumes. One of these treatments was designated as "check". The other three treatments consisted of varying increments of ammonium nitrate applied as a side-dressing to the corn approximately three to four weeks after emergence of the seedlings. These three treatments were designated N_1, N_2 and N_3. Ammonium nitrate fertilizer was applied with a properly calibrated Planet Junior but due to variations in soil conditions at the time of side-dressing, the amount delivered varied from experiment to experiment. The actual amounts applied are presented in Table 2.

5. Methods of harvesting and processing legumes

Following a killing frost in the fall, samples were obtained from the legume seedings for the purpose of estimating the yields of aerial and subterranean parts of the plants. In 1952, four quadrats measuring 18" x 18" were taken in each legume plot according to the plan shown in Fig. 1. The exact location of a particular quadrat was in each case determined by the author alone, with the view of including in that sample an area representative of that quarter of the plot in which the quadrat was located. In 1951, a somewhat different procedure had been used: two quadrats, each measuring 36" x 18" were utilized. The approximate position of these samples was similar to that of two diagonnally opposite quadrats sampled in 1952.

A three-sided one-half inch pipe frame was used to delimit the quadrat areas. Following the placement of this frame on the ground surface (after careful parting of the vegetation), a trench approximately eight inches in width and twelve to fifteen inches in depth was dug around the quadrat to form a block of soil, 18" x 18" or 36" x 18" in area, as the case might be, which was then lifted onto a canvas. The root sampling method was similar to that used by Willard (98). In the case of roots extending beyond the fifteen- to eighteen-inch depth, some further spade work was necessary. The majority of the soil was then crumbled off the roots by hand, generally leaving soil particles of less than one quarter-inch diameter adhering to the roots.

The samples were then placed into cloth bags and labeled with a previously stamped metal tag. Then the samples were either further processed the following day or they were stored at low temperature until such time as they could be handled through the next stage, the elapsed time never exceeding six days.

The tops were severed from the roots at the crown; in the case of ladino clover, the stolons were included in the tops. The lower parts of the erect stems, as well as the ladino stolons, were washed free of soil under a faucet. In 1951, the legume roots were washed by hand under a faucet. This method was very time-consuming, particularly in view of the large number of samples processed. In 1952, mechanical washing was introduced (28). The root samples were placed separately in 14" x 9" x 2" trays with wooden sides and eight by eight hardware-cloth bottoms. These trays were then stacked, fourteen at a time, in a 50-gallon drum previously filled with water containing one pound of a wetting agent (Calgon). The top tray was covered with hardware-cloth to prevent loss of roots. The fourteen trays, securely held together by metal straps, were raised and lowered into the drum four times, at half-hour intervals

Fig. 2. Stack of fourteen root trays prior to immersion in drum filled with water and wetting agent

Fig. 3. Overhead sprinkling of previously soaked root samples

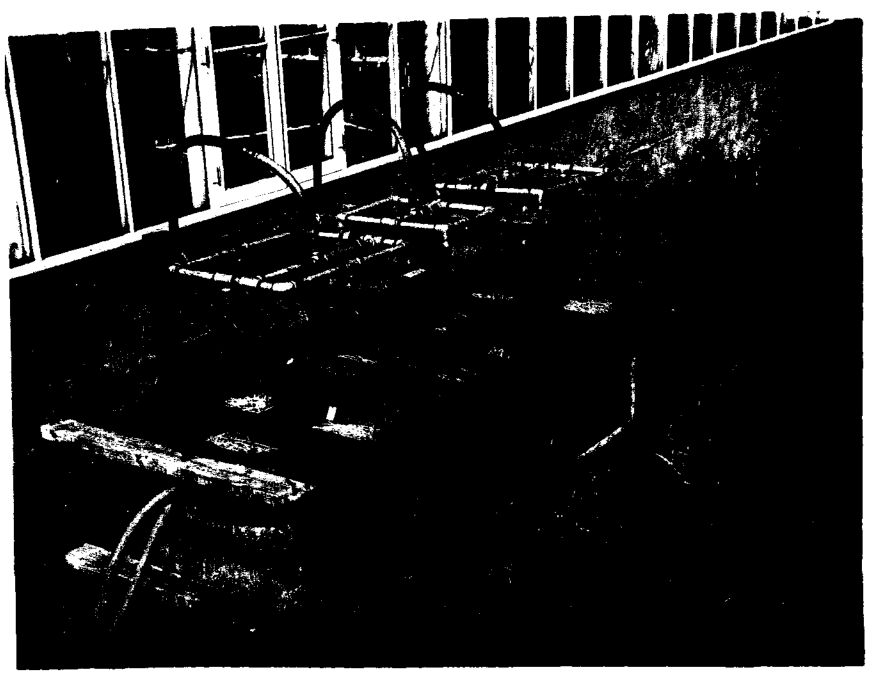
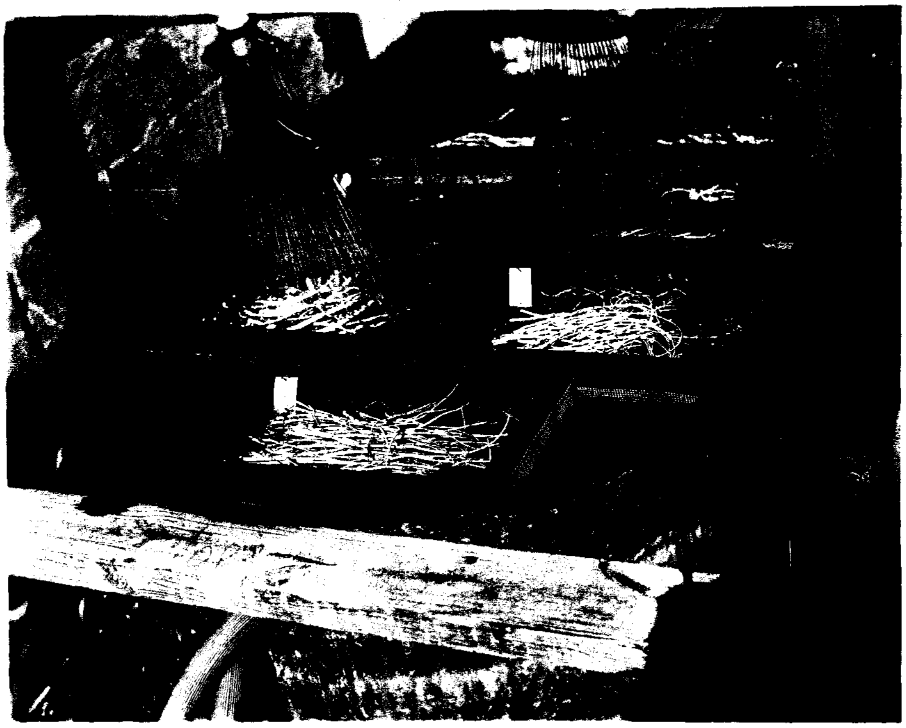
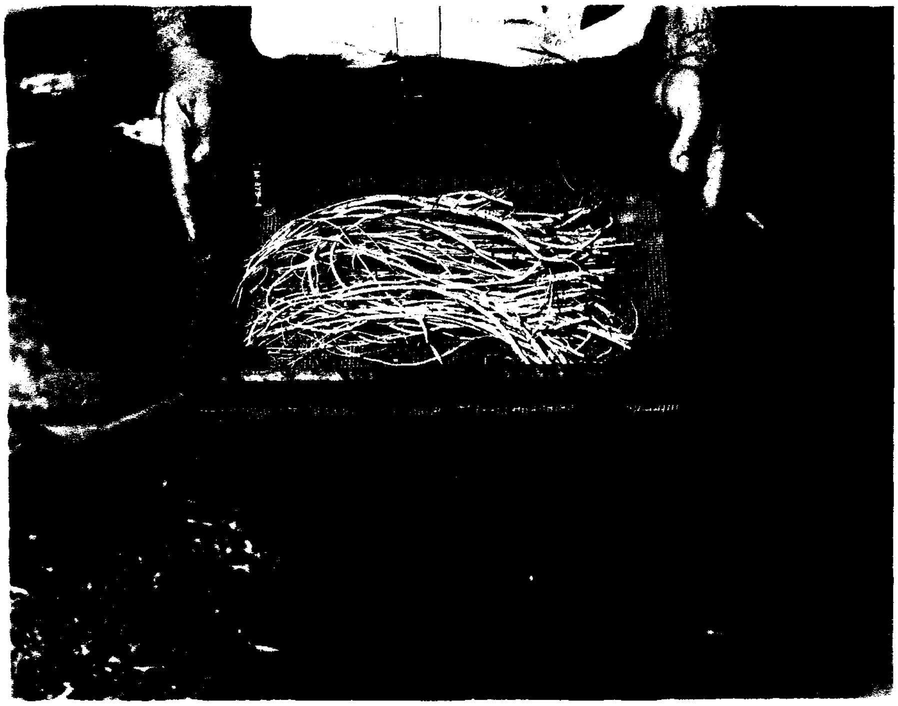


Fig. 4. Close-up view of overhead sprinkling apparatus

Fig. 5. Close-up view of clean roots





(Fig. 2).

Following this immersion, which loosened and dispersed some of the soil, the fourteen trays were placed on a slatted platform raised twenty-four inches from the bottom of an 8' x 3' x 3' watering tank (Fig. 3). A one-hour sprinkling by means of overhead sprinkling nozzles, one over each tray (Fig. 4) completed the washing process and resulted in clean roots (Fig. 5).

After washing, the tops and roots were dried in a 70°C oven and weighed to the nearest gram. Previous work indicated that this oven dried plant material (corn) to 1.4% moisture (56). The top and root samples from a particular plot were then composited separately and ground in a Wiley mill to pass a 40-mesh sieve, in preparation for subsequent chemical analysis.

6. Methods of harvesting and sampling corn

During the month of July, leaf samples were obtained according to the method proposed by Tyner (82) and verified as to its usefulness by others (1 , 7). The actual dates of sampling for each location each year are presented in Table 2. The leaf blade just below and opposite the primary ear was removed from one plant in each of the ten hills that were to be harvested in the fall (see Fig. 1). Sampling was done, inasmuch as possible, when the plants were silked out and shedding pollen. Unfortunately, due to practical and economic reasons, there were times when the sampling was done at a stage of development of the corn plants somewhat different from the ideal one. The effects resulting from these difficulties will be examined in the presentation of results and their discussion. The leaf samples were dried in a 70°C oven, ground in a Wiley mill to pass through a 40-mesh sieve and stored for later chemical analysis.

In the fall, stand counts were taken on a plot basis, and the ears harvested from the center ten hills in each plot. Only competitive hills were harvested. A record was made of the number of good ears and nubbins harvested from each plot. The ears were then shelled, and both the grain and the cobs dried in a 70°C oven to 1.4% moisture (56). Weights for both shelled corn and cobs were recorded to the nearest gram.

7. Chemical analyses

The corn leaf samples and legume tops and roots were analyzed for total nitrogen content according to Winkler's modification of the Kjeldahl method (66 , 68). A 1.5 gram sample was used. Potassium and copper sulfates were utilized as digestion catalysts. The ammonium acid borate was titrated with fourteenth normal sulfuric acid, using a mixture of methyl red and brom cresol green as indicator.

8. Presentation of data and statistical analysis

Dry matter yields of legume tops and legume roots are presented in terms of oven-dry yields in pounds per acre. From these data and the percent nitrogen for each sample, yields of nitrogen were computed in pounds per acre. In addition to these data, the ratios of tops to roots were calculated for both dry matter and nitrogen yields, as well as the total (tops plus roots) yields of dry matter and nitrogen in pounds per acre.

Nitrogen in the corn leaf at silking time is presented as a percentage on the dry weight basis. Yields of shelled corn are given in bushels of corn per acre on a 1.4% moisture basis. The dry weight yields of cobs in tons per acre are also tabulated, as well as the shelling percentages calculated from the original weights in grams of the plot yields. The mean stand per treatment also has been included in the presentation of results.

All data for each location and each year were subjected to the accepted procedures of statistical analysis. For reasons that will be apparent after examination of the data obtained, and in view of the previously stated objectives of the study, a combined statistical analysis of the data for all locations and years was not made. The mathematical procedure used to associate the results obtained at different locations and in different years will be delineated in the discussion of results.

For the purpose of differentiating between treatment means, the sequential range test was utilized. This test is based on a procedure used by "Student" which was first mentioned by Newman (57) in connection with the analysis of variance and further elaborated upon by Keuls (42). The sequential range test enables the testing of the hypothesis that the range between any two means is not significantly different from zero at a particular level of significance. In using this test in this study, the five percent level of significance was adopted throughout as the point for rejection of the hypothesis.

B. Preliminary Studies on Other Legumes

Two preliminary studies of a relatively large number of legumes were conducted at the Agronomy Farm, Ames, one in 1952 and the other in 1953.

1. 1952 preliminary study

Twenty-seven legumes were hand-broadcasted after inoculation with the proper strains of Rhizobia on April 17 with drilled Cherokee oats. In the main, these plots received the same agronomic treatments as the seedings in the Green Manure Study, with the exception that no fertilizer was applied at the time of planting. The design was a randomized complete block with four replications; the plots measured 6' x 12', and were arranged in three ranges of nine plots in each replication. The legumes used and the rates of seeding utilized are presented in Table 3.

In July, following removal of the oats for grain, notes were obtained for each plot as to the following characteristics: stand, plant vigor, height and yield estimate. Plant height was measured in inches and the other three characters were recorded on the basis of an index scale from one to ten, the larger numbers of the range referring to either a denser stand, an apparently more vigorous vegetation, or a higher estimate of yield in each case, respectively. Plant vigor was recorded on the basis of the plants present, whereas a stand of 10 was considered to be present when the soil surface was hidden by leguminous vegetation. Yield was estimated on a relative basis as a composite of the other three

Table 3. Legumes studied and rates of seeding in the 1952 preliminary study at Ames, Iowa

Legumes Latin name	Common name	Variety or strain	Viable seeds lbs./A
Chamaecrista fasciculata	partridge pea	-	15
Dalea alopecuroides	woods clover	-	15
Lespedeza hedysaroides	rush lespedeza	-	14
" stipulacea	Korean lespedeza	Iowa 6	14
Lotus corniculatus	birdsfoot trefoil	Italian	8
Lupinus angustifolius	blue lupine	Alta	85
Medicago sativa	alfalfa	Africa	15
" "	"	Chilean 21-5	15
" "	"	Grimm	15
" "	"	India	15
" "	"	southern common (Calif.)	15
Melilotus alba (annua)	white sweetclover	Floranna	15
" " "	" "	Hubam	14
" officinalis	yellow sweetclover	Madrid	14
Trifolium alexandrinum	berseem clover	-	20
" hirtum	rose clover	-	15
" hybridum	alsike clover	-	12
" incarnatum	crimson clover	Dixie	20
" lappaceum	lappa clover	-	5
" pratense	red clover	mammoth	12
" "	" "	medium	12
" procumbens	large hop clover	-	4
" repens	white clover	Ladino	3
" resupinatum	Persian clover	-	5
" subterraneum	sub clover	Tallarook	25
Vicia sativa	common vetch	-	75
" villosa	hairy vetch	-	40

factors measured and such other conditions conceivably affecting yield potential, such as disease or insect infestation.

On September 18 two 18" x 18" quadrats were harvested for the following legumes: Madrid sweetclover, medium and mammoth red clovers, hairy vetch, Dixie crimson clover and Iowa 6 lespedeza. Both aerial and subterranean parts were processed according to the methods outlined for legume sampling in the Green Manure Study, and dry weight yields and nitrogen contents were obtained.

2. 1953 preliminary study

On the basis of results obtained in 1952, fifteen legumes were hand-broadcasted after inoculation with the proper strains of Rhizobia on April 8 with drilled Cherokee oats, following applications of one-half pound per acre of pre-emergence Dieldrin and 200 pounds per acre of broadcast and disced in 4-16-8 fertilizer. Other agronomic management was similar to that followed in the Green Manure Study. The design was a randomized complete block design with four replications. The plots measured 13'4" x 23'4", and were arranged in three ranges of five plots in each replication. Legumes used and the seeding rates utilized are presented in Table 4.

In late October, four 18" x 18" quadrats were harvested of the following legumes: southern common alfalfas A, B and C, mammoth and medium red clovers, Iowa 6 lespedeza and hairy vetch. Due to severe drouth in midsummer and fall, it was not feasible to harvest the roots of these legumes; however, the tops were cut below ground with a horizontally-bladed "scalping hoe". The yields were measured on the aerial parts as

Table 4. Legumes studied and rates of seeding in the 1953 preliminary study at Ames, Iowa

Legumes: Latin name	Legumes: Common name	Variety or strain	Viable seeds lbs./A
Chamaecrista fasciculata	partridge pea	-	100
Lespedeza stipulacea	Korean lespedeza	Iowa 6	16
Lotus corniculatus	birdsfoot trefoil	Empire	14
" "	" "	Italian	12
Medicago sativa	alfalfa	Grimm	13
" "	"	southern common A[1]	13
" "	"	" " B	13
" "	"	" " C	13
Melilotus alba(annua)	white sweetclover	Hubam	11
" officinalis	yellow sweetclover	Madrid	12
Trifolium incarnatum	crimson clover	Dixie	21
" pratense	red clover	mammoth	11
" "	" "	medium	11
" repens	white clover	Ladino	3.5
Vicia villosa	hairy vetch	-	31

[1]Lot A is the same lot as that from which the southern common alfalfa seed used in the Green Manure Study was taken. Southern common alfalfas B and C are from different lots.

defined in the Green Manure Study. The samples were processed in the same way as for other similar samples, and analyzed for total nitrogen content.[1]

The same statistical and chemical procedures used in the Green Manure Study were followed with respect to both the 1952 and the 1953 preliminary studies.

C. Corn Response and Residual Effects from Freshly-Cut and Other Crop Residues

This study consisted of two experiments conducted at the Agronomy Farm, Ames, during 1952 and 1953. The experimental area encompassed three different soil types, namely Clarion loam and/or silt loam, Nicollet loam and Webster silty clay loam, the Nicollet predominating in the field. Various nitrogen-containing organic materials were applied on May 17 and 18 at varying rates and disced in following a blanket application of 300 pounds per acre of 0-20-20 fertilizer. Iowa Hybrid 4298 corn was hand-planted on May 20 at the rate of six kernels per hill; the stand was thinned four weeks later to a final average population of 15,840 stalks per acre at maturity. The experimental design was a randomized complete block with four replications, each replication consisting of three ranges of seven plots each. The plots measured 13'4" x 23'4", thus containing four rows each with seven hills of corn from which the center ten hills were harvested for yield.

---

[1] Thanks are extended to Dr. H. E. Thompson and Mr. G. W. Wengert, Department of Agronomy, Iowa State College, who harvested and analyzed the samples from this experiment.

The treatments studied are presented in Table 5, together with the symbols by which they will be referred to subsequently. In addition to the organic materials disced in prior to corn-planting, various rates of ammonium nitrate were side-dressed at the time of corn-thinning. The check treatment, which received no organic or inorganic nitrogen, included eight plots (two in each replication). The freshly harvested alfalfa and medium red clover were cut on fields neighbouring the experimental location, and applied to the appropriate plots within twenty-four hours after mowing. The soybean straw had been produced on the Agronomy Farm the previous year and allowed to stand outdoors over winter. The oat hulls were obtained through the courtesy of Mr. John Sand, Marcus, Iowa.

These organic materials were analyzed for total nitrogen content on a plot basis. However, the sample analyzed (according to the method described for the Green Manure Study chemical analyses) was a composite of samples obtained at the time of application at the rate of one two-pound sample for each thirty pounds of applied material. Analysis of variance of these nitrogen contents indicated no significant differences among plots for each source of nitrogen material. Therefore, a mean nitrogen content was used for the calculation of amounts of nitrogen applied per acre from each source.

The same kind of data was obtained for each corn plot as was measured for the corn plots in the Green Manure Study, namely corn leaf percent nitrogen (sampled on July 28), yield of shelled corn and cobs (harvested on October 11), shelling percentage and stand. The data

Table 5. Rates of application of organic and inorganic sources of nitrogen in 1952 at Ames, Iowa

Treatment Symbol	Kind	Materials applied: Amount (dry matter) lbs./A	Percent Nitrogen	Amount N lbs./A
A 1	Freshly-cut alfalfa	770	3.68	28.3
A 2	"	1540	3.68	56.7
A 3	"	3080	3.68	113.4
A 4	"	4621	3.68	170.0
RC 1	Freshly-cut medium red clover	886	3.90	34.5
RC 2	"	1771	3.90	69.1
RC 3	"	3542	3.90	138.2
RC 4	"	5314	3.90	207.2
SB 1	Soybean straw	2660	.96	25.5
SB 2	"	5321	.96	51.1
SB 3	"	10641	.96	102.2
SB 4	"	15962	.96	153.2
OH	Oat hulls	23277	.98	228
SB-N3	Soybean straw +	10641	.96	102.2
	Ammonium nitrate	147.5	33.4	49.4
N 1	Ammonium nitrate	32.2	33.4	10.8
N 2	"	59.1	33.4	19.8
N 3	"	147.5	33.4	49.4
N 4	"	331.6	33.4	111.0
N 5	"	498.8	33.4	166.9
Check	None	--	--	--

were also analyzed in a similar manner.

In 1953, the plots used in the previous year were divided into three equal parts measuring 13'4" x 7'9 1/3". Following a blanket application of 200 pounds per acre of 0-45-54 fertilizer equivalent, Clintafe oats were drilled on April 6 at the rate of two bushels per acre. The three sub-plots were assigned at random to three treatments involving the hand-broadcasting just prior to oats-planing of none, fifteen and thirty pounds of nitrogen per acre in the form of ammonium nitrate.

At the time when oats in the farthest advanced plots were coming out of the boot (July 17-19), an area measuring 3'6" x 9' was harvested with a power sickle bar mower from the center of each sub-plot. The samples were dried, weighed, ground through a Wiley mill to pass a 40-mesh sieve, and analyzed for total nitrogen content. The "nitrogen recovery" was determined from the product of the dry weight of the oats and the nitrogen content of the sample from each individual sub-plot. These data are expressed in terms of pounds of nitrogen recovered per acre.

IV. EXPERIMENTAL RESULTS

A. Green Manure Experiments

1. Legume growth and characteristics

The yields of dry matter and nitrogen in pounds per acre, the nitrogen contents of the tops and roots, and the ratios of tops to roots for dry matter and nitrogen yields are presented in Tables 6 through 13. The sequential range test was used for testing of significant differences among treatment means. As a result, no analyses of variance are presented. Rather, each table of means is followed by a series of the statements that can be justifiably made as to the statistically significant differences between legumes for each character measured.

a. Growth and characteristics of legumes grown in 1951. In 1951, the D.D.T. sprays and dust applications did not adequately control sweetclover weevil infestations at any of the four locations. The damage was slightly less at Kanawha than at the other locations. There also was a severe attack of summer black stem, *Cercospora zebrina* Pass. on the alfalfas at Ames, Clarinda and Marcus, and to a lesser degree at Kanawha. Due to these two causes, as well as to the wet and late spring, the stands of alfalfas and sweetclovers were sparse and the yields low.

Since Hubam sweetclover is an annual, it blooms in Iowa in the second half of August or early September. By the time samples were obtained after a killing frost, the plants had lost the majority of their

Table 6. Yields of dry matter and nitrogen in pounds per acre, nitrogen percentages, and top-root ratios of legumes grown at Ames in 1951
(Means of four replications, two quadrats per plot)

		Grimm Alfalfa	Southern Common Alfalfa	Madrid Sweet-clover	Hubam Sweet-clover	Medium Red Clover	Ladino Clover
Dry matter yield	Tops	233	305	488	306	1 385	2 271
	Roots	150	122	423	42	638	664
	Tops + roots	383	427	911	348	2 023	2 935
Percent nitrogen	Tops	3.07	2.98	2.63	2.02	2.72	3.18
	Roots	2.50	2.06	2.51	1.90	2.38	2.10
Nitrogen yield	Tops	7.4	9.0	13.2	6.6	38.0	71.8
	Roots	3.9	2.5	11.5	0.8	15.2	14.0
	Tops + roots	11.3	11.5	24.7	7.4	53.2	85.8
Tops/Roots	Dry matter	1.57	2.48	1.32	7.30	2.25	3.58
	Nitrogen	1.90	3.62	1.34	8.52	2.58	5.34

Table 7. Yields of dry matter and nitrogen in pounds per acre, nitrogen percentages, and top-root ratios of legumes grown at Clarinda in 1951
(Means of four replications, two quadrats per plot)

		Grimm Alfalfa	Southern Common Alfalfa	Madrid Sweet-clover	Hubam Sweet-clover	Medium Red Clover	Ladino Clover
Dry matter yield	Tops	266	276	438	177	1 450	1 281
	Roots	287	176	420	50	698	490
	Tops + roots	553	452	858	227	2 148	1 771
Percent nitrogen	Tops	2.90	2.70	2.52	2.15	2.90	2.84
	Roots	1.97	1.62	1.56	1.57	2.63	2.32
Nitrogen yield	Tops	7.7	7.7	10.8	3.9	42.0	36.4
	Roots	5.6	2.9	6.7	.8	18.5	11.1
	Tops + roots	13.3	10.6	17.5	4.7	60.5	47.5
Tops/Roots	Dry matter	.96	1.64	1.18	5.31	2.04	2.97
	Nitrogen	1.37	2.58	1.86	5.90	2.34	3.48

leaves, the stems were usually dried up and the roots were beginning to decompose. Low yields and nitrogen contents of Hubam sweetclover as presented here are therefore due, in part at least, to late harvest.

From the analysis of sequential range, the following legumes, grown at Ames in 1951, were significantly different at the 5% level+

Dry Matter Yield

Yield of tops

Ladino exceeded Grimm, common alfalfas, Hubam, Madrid and red clover

Red clover exceeded Grim, common alfalfa, Hubam and Madrid

Yield of roots

Red clover and Ladino exceeded Hubam, common alfalfa and Grimm

Total dry matter

Ladino exceeded Hubam, Grimm, common alfalfa, Madrid and red clover

Red clover exceeded Hubam, Grimm, common alfalfa and Madrid

Nitrogen Yield

Yield of tops

Ladino exceeded Hubam, Grimm, common alfalfa, Madrid and red clover

Red clover exceeded Hubam, Grimm, common alfalfa and Madrid

Yield of roots

Ladino and red clover exceeded Hubam, common alfalfa and Grimm

Madrid exceeded Hubam

Total nitrogen yield

Ladino exceeded Hubam, Grimm, common alfalfa, Madrid and red clover

Red clover exceeded Hubam, Grimm, common alfalfa and Madrid

Percent Nitrogen

Tops

Ladino, Grimm, common alfalfa, red clover and Madrid exceeded Hubam

Ladino exceeded Madrid

Roots

Madrid and Grimm exceeded Hubam

From the analysis of sequential range, the following legumes, grown at Clarinda in 1951, were significantly different at the 5% level:

Dry Matter Yield

Yield of tops

Ladino and red clover exceeded Hubam, Grimm, common alfalfa and Madrid

Yield of roots

Red clover exceeded Hubam, common alfalfa and Grimm

Ladino and Madrid exceeded Hubam

Total dry matter

Ladino and red clover exceeded Hubam, common alfalfa, Grimm and Madrid

Nitrogen Yield

Yield of tops

Red clover and ladino exceeded Hubam, common alfalfa, Grimm and Madrid

Table 8. Yields of dry matter and nitrogen in pounds per acre, nitrogen percentages, and top-root ratios of legumes grown at Kanawha in 1951
(Means of four replications, two quadrats per plot)

		Grimm Alfalfa	Southern Common Alfalfa	Madrid Sweet-clover	Hubam Sweet-clover	Medium Red Clover	Ladino Clover
Dry matter yield	Tops	1232	1577	660	249	1898	2724
	Roots	606	499	490	40	527	458
	Tops + roots	1838	2076	1150	289	2425	3182
Percent nitrogen	Tops	3.35	3.35	3.53	3.07	3.10	3.41
	Roots	3.64	3.34	3.76	2.53	3.23	3.28
Nitrogen yield	Tops	41.0	53.0	22.9	7.7	58.5	91.8
	Roots	22.0	16.5	18.4	1.0	17.0	15.0
	Tops + roots	63.0	69.5	41.3	8.7	75.5	106.8
Tops/Roots	Dry matter	2.17	3.62	1.53	7.04	3.66	2.78
	Nitrogen	1.90	3.26	1.35	10.46	3.51	6.32

Table 9. Yields of dry matter and nitrogen in pounds per acre, nitrogen percentages, and top-root ratios of legumes grown at Marcus in 1951
(Means of three replications, two quadrats per plot)

		Grimm Alfalfa	Southern Common Alfalfa	Madrid Sweet-clover	Hubam Sweet-clover	Medium Red Clover	Ladino Clover
Dry matter yield	Tops	778	680	249	156	1675	2769
	Roots	407	188	94	17	630	710
	Tops + roots	1185	868	343	173	2305	3479
Percent nitrogen	Tops	3.34	3.28	3.36	2.56	3.09	3.13
	Roots	2.61	1.90	2.92	1.43	2.44	2.28
Nitrogen yield	Tops	25.8	22.8	8.3	3.9	51.6	86.2
	Roots	10.7	3.6	2.7	.2	15.3	16.1
	Tops + roots	36.5	26.4	11.0	4.1	66.9	102.3
Tops/Roots	Dry matter	2.06	3.54	3.02	8.84	2.79	3.27
	Nitrogen	2.43	6.14	3.29	15.86	3.34	5.29

Yield of roots

Red clover exceeded Hubam, common alfalfa, Grimm, Madrid and ladino

Ladino exceeded Hubam and common alfalfa

Total nitrogen

Ladino and red clover exceeded Hubam, common alfalfa, Grimm and Madrid

Percent Nitrogen

Tops

Red clover, Grimm, ladino, common alfalfa and Madrid exceeded Hubam

Roots

Ladino and red clover exceeded Madrid, Hubam, common alfalfa and Grimm

From the analysis of sequential range, the following legumes, grown at Kanawha in 1951, were significantly different at the 5% level:

Dry Matter Yield

Yield of tops

Ladino exceeded Hubam, Madrid, Grimm, common alfalfa and red clover

Red clover exceeded Hubam, Madrid and Grimm

Grimm and common alfalfa exceeded Hubam and Madrid

Madrid exceeded Hubam

Yield of roots

Grimm, red clover, common alfalfa, Madrid and ladino exceeded Hubam

Total dry matter

Ladino exceeded Hubam, Madrid, Grimm, common alfalfa and red clover

Red clover, common alfalfa and Grimm exceeded Hubam and Madrid

Madrid exceeded Hubam

Nitrogen Yield

Yield of tops

Ladino exceeded Hubam, Madrid, Grimm, common alfalfa and red clover

Red clover and common alfalfa exceeded Hubam, Madrid and Grimm

Grimm exceeded Hubam and Madrid

Madrid exceeded Hubam

Yield of roots

Grimm, Madrid, red clover, common alfalfa and ladino exceeded Hubam

Total nitrogen yield

Ladino exceeded Hubam, Madrid, Grimm, common alfalfa and red clover

Red clover, common alfalfa and Grimm exceeded Hubam and Madrid

Madrid exceeded Hubam

Percent Nitrogen

Tops

No legume exceeded any other

Roots

Madrid, Grimm, common alfalfa, ladino and red clover exceeded Hubam

From the analysis of sequential range, the following legumes, grown at Marcus in 1951, were significantly different at the 5% level:

Dry Matter Yield

Yield of tops

Ladino exceeded Hubam, Madrid, common alfalfa, Grimm and red clover

Red clover exceeded Hubam, Madrid, common alfalfa and Grimm

Yield of roots

Ladino and red clover exceeded Hubam, Madrid, common alfalfa and Grimm

Grimm exceeded Hubam, Madrid and common alfalfa

Total dry matter

Ladino and red clover exceeded Hubam, Madrid, common alfalfa and Grimm

Ladino exceeded red clover

Nitrogen Yield

Yield of tops

Ladino and red clover exceeded Hubam, Madrid, common alfalfa and Grimm

Ladino exceeded red clover

Yield of roots

Ladino and red clover exceeded Hubam, Madrid, common alfalfa and Grimm

Grimm exceeded Hubam, Madrid and common alfalfa

Total nitrogen yield

Ladino and red clover exceeded Hubam, Madrid, common alfalfa and Grimm

Ladino exceeded red clover

Percent Nitrogen

Tops

Madrid, Grimm, common alfalfa, ladino and red clover exceeded Hubam

Roots

Madrid exceeded Hubam, common alfalfa and ladino

Grimm and red clover exceeded Hubam and common alfalfa

Ladino and common alfalfa exceeded Hubam

In general, in 1951, medium red and ladino clovers were significantly higher yielding than the other four legumes with respect to both dry matter and nitrogen. Medium red clover yielded between 2000 and 2400 pounds of dry matter per acre, containing between 50 and 75 pounds of nitrogen; on the other hand, the dry matter yields of ladino clover varied between 1800 and 3500 pounds, equivalent to 50 to 100 pounds of nitrogen per acre. Even though there was an apparently greater variation in ladino clover yields from location to location, this legume was superior to medium red clover at three out of the four experimental sites.

At Kanawha, the alfalfa yields of dry matter were nearly 2000 pounds per acre, equivalent to approximately 65 pounds of nitrogen, and significantly higher than yields of sweetclover. At all locations, the sweetclovers were the lowest in yield, and usually Hubam was inferior to Madrid.

Little difference existed among legumes as to nitrogen percentage of tops or roots. Hubam, and oftentimes Madrid, were significantly lower than the other legumes, whereas ladino and occasionally red clover tended to be higher in nitrogen content. However, in view of the low magnitude of the ranges in percent nitrogen, it would not seem that even those differences which were statistically different between legumes would be of great agronomic meaning. The top-root ratios will be discussed following the presentation of the 1952 dry matter yield and nitrogen data for the six legumes.

b. Growth and characteristics of legumes grown in 1952.

From the analysis of sequential range, the following legumes, grown at Ames in 1952, were significantly different at the 5% level:

Dry Matter Yield

Yield of tops

Madrid and ladino exceeded red clover, Grimm, Hubam and common alfalfa

Madrid exceeded ladino

Common alfalfa exceeded red clover and Grimm

Yield of roots

Madrid exceeded Hubam, red clover, ladino, Grimm and common alfalfa

Grimm and common alfalfa exceeded Hubam, red clover and ladino

Red clover and ladino exceeded Hubam

Total dry matter

Madrid exceeded Hubam, red clover, Grimm, common alfalfa and ladino

Common alfalfa and ladino exceeded Hubam and red clover

Table 10. Yields of dry matter and nitrogen in pounds per acre, nitrogen percentages, and top-root ratios of legumes grown at Ames in 1952
(Means of four replications, four quadrats per plot)

		Grimm Alfalfa	Southern Common Alfalfa	Madrid Sweet-clover	Hubam Sweet-clover	Medium Red Clover	Ladino Clover
Dry matter yield	Tops	1 248	1 539	2 732	1 363	1 214	2 291
	Roots	990	1 110	2 221	307	531	576
	Tops + roots	2 238	2 649	4 953	1 670	1 745	2 867
Percent nitrogen	Tops	3.02	2.74	2.30	1.42	2.69	3.04
	Roots	2.57	2.27	3.36	2.33	2.20	2.46
Nitrogen yield	Tops	37.7	42.2	62.9	19.7	32.8	69.8
	Roots	25.5	25.1	74.1	7.2	11.8	13.9
	Tops + roots	63.2	67.3	137.0	26.9	44.6	83.7
Tops/Roots	Dry matter	1.32	1.48	1.29	5.20	2.31	4.64
	Nitrogen	1.50	1.75	0.86	2.86	2.81	5.47

Table 11. Yields of dry matter and nitrogen in pounds per acre, nitrogen percentages, and top-root ratios of legumes grown at Clarinda in 1952
(Means of four replications, four quadrats per plot)

		Grimm Alfalfa	Southern Common Alfalfa	Madrid Sweet-clover	Hubam Sweet-clover	Medium Red Clover	Ladino Clover
Dry matter yield	Tops	1 406	1 427	3 785	2 001	531	1 643
	Roots	1 288	1 038	2 540	301	307	312
	Tops + roots	2 694	2 465	6 325	2 302	838	1 955
Percent nitrogen	Tops	2.70	2.70	2.15	1.28	3.09	2.71
	Roots	2.46	1.99	2.86	1.92	2.16	2.07
Nitrogen yield	Tops	38.0	38.5	81.1	25.1	16.5	44.6
	Roots	32.4	21.0	72.5	6.6	6.7	6.3
	Tops + roots	70.4	59.5	153.6	31.7	23.2	50.9
Tops/Roots	Dry matter	1.10	1.35	1.67	8.63	1.76	5.20
	Nitrogen	1.23	1.92	1.20	6.83	2.62	6.77

Nitrogen Yield

Yield of tops

Madrid and ladino exceeded Hubam, red clover, Grimm and common alfalfa

Red clover, Grimm and common alfalfa exceeded Hubam

Yield of roots

Madrid exceeded Hubam, red clover, ladino, common alfalfa and Grimm

Common alfalfa and Grimm exceeded Hubam, red clover and ladino

Total nitrogen yield

Madrid exceeded Hubam, red clover, Grimm, common alfalfa and ladino

Ladino, common alfalfa and Grimm exceeded Hubam and red clover

Red clover exceeded Hubam

Percent Nitrogen

Tops

Ladino, Grimm, common alfalfa, red clover and Madrid exceeded Hubam

Ladino and Grimm exceeded Madrid

Roots

Madrid exceeded red clover, common alfalfa, Hubam, ladino and Grimm

From the analysis of sequential range, the following legumes, grown at Clarinda in 1952, were significantly different at the 5% level:

Dry Matter Yield

Yield of tops

Madrid exceeded red clover, Grimm, common alfalfa, ladino and Hubam

Hubam exceeded red clover, Grimm and common alfalfa

Ladino, common alfalfa and Grimm exceeded red clover

Yield of roots

Madrid and Grimm exceeded Hubam, red clover, ladino and common alfalfa

Madrid exceeded Grimm

Common alfalfa exceeded Hubam, red clover and ladino

Total dry matter

Madrid exceeded red clover, ladino, Hubam, common alfalfa and Grimm

Grimm, common alfalfa, Hubam and ladino exceeded red clover

Nitrogen Yield

Yield of tops

Madrid exceeded red clover, Hubam, Grimm, common alfalfa and ladino

Ladino exceeded red clover

Yield of roots

Madrid exceeded ladino, Hubam, red clover, common alfalfa and Grimm

Grimm exceeded ladino, Hubam and red clover

Total nitrogen yield

Madrid exceeded red clover, Hubam, ladino, common alfalfa and

Grimm

Grimm exceeded red clover and Hubam

Common alfalfa exceeded red clover

Percent Nitrogen

Tops

Red clover exceeded Hubam, Madrid, Grimm, common alfalfa and ladino

Ladino, Grimm and common alfalfa exceeded Hubam and Madrid

Madrid exceeded Hubam

Roots

Madrid exceeded Hubam, common alfalfa, ladino and red clover

As a result of an unfortunate misunderstanding, two of the four replications of legumes grown at Kanawha in 1952 were mowed closely in late July. This clipping resulted in different responses from each of the several legumes. Those effects will be discussed later on (Table 16). In the evaluation of legumes for green manure purposes, therefore, only the two replications which were not clipped were utilized.

From the analysis of sequential range, the following legumes, grown at Kanawha in 1952, were significantly different at the 5% level:

Dry Matter Yield

Yield of tops

Madrid and Hubam exceeded red clover, common alfalfa, Grimm and ladino

Ladino exceeded red clover, common alfalfa and Grimm

Yield of roots

Madrid and Grimm exceeded Hubam, ladino, red clover and common

Table 12. Yields of dry matter and nitrogen in pounds per acre, nitrogen percentages, and top-root ratios of legumes grown at Kanawha in 1952
(Means of two replications, four quadrats per plot)

		Grimm Alfalfa	Southern Common Alfalfa	Madrid Sweet-clover	Hubam Sweet-clover	Medium Red Clover	Ladino Clover
Dry matter yield	Tops	1 878	1 841	3 014	3 052	1 483	2 417
	Roots	1 152	843	1 488	149	390	251
	Tops + roots	3 030	2 684	4 502	3 201	1 873	2 668
Percent nitrogen	Tops	3.48	3.34	2.85	2.83	3.36	3.23
	Roots	2.75	2.44	3.42	1.14	2.35	2.30
Nitrogen yield	Tops	65.2	61.6	85.8	86.4	49.4	78.1
	Roots	31.7	20.4	50.8	1.7	9.2	5.8
	Tops + roots	96.9	82.0	136.6	88.1	58.6	83.9
Tops/Roots	Dry matter	1.62	2.20	2.10	17.83	3.83	10.02
	Nitrogen	2.04	3.00	1.69	51.78	5.46	13.58

Table 13. Yields of dry matter and nitrogen in pounds per acre, nitrogen percentages, and top-root ratios of legumes grown at Marcus in 1952
(Means of four replications, four quadrats per plot)

		Grimm Alfalfa	Southern Common	Madrid Sweet-clover	Hubam Sweet-clover	Medium Red Clover	Ladino Clover
Dry matter yield	Tops	2 249	2 582	2 977	2 134	1 606	2 334
	Roots	1 651	1 705	1 838	582	611	600
	Tops + roots	3 900	4 287	4 815	2 716	2 217	2 934
Percent nitrogen	Tops	3.37	3.10	3.06	2.62	3.22	2.79
	Roots	2.72	2.42	2.52	2.47	2.41	2.27
Nitrogen yield	Tops	74.6	78.5	90.1	55.7	51.6	64.2
	Roots	44.5	41.0	46.1	14.2	14.8	13.1
	Tops + roots	119.1	119.5	136.2	69.9	66.4	77.3
Tops/Roots	Dry matter	1.38	1.52	1.62	3.74	2.69	4.06
	Nitrogen	1.68	1.92	1.96	3.95	3.53	4.86

alfalfa

Madrid exceeded Grimm

Common alfalfa and red clover exceeded Hubam and ladino

Common alfalfa exceeded red clover

Total dry matter

Madrid exceeded red clover, ladino, common alfalfa, Grimm and Hubam

Hubam exceeded red clover

Nitrogen Yield

Yield of tops

Hubam, Madrid and ladino exceeded red clover

Yield of roots

Madrid and Grimm exceeded Hubam, ladino, red clover and common alfalfa

Madrid exceeded Grimm

Common alfalfa exceeded Hubam, ladino and red clover

Red clover exceeded Hubam

Total nitrogen yield

Madrid exceeded red clover, common alfalfa, ladino, Hubam and Grimm

Grimm exceeded red clover

Percent Nitrogen

Tops

Grimm, red clover, common alfalfa and ladino exceeded Hubam and Madrid

Roots

Madrid and Grimm exceeded Hubam, ladino, red clover and common alfalfa

Madrid exceeded Grimm

Common alfalfa, red clover and ladino exceeded Hubam

From the analysis of sequential range, the following legumes, grown at Marcus in 1952, were significantly different at the 5% level:

Dry Matter Yield

Yield of tops

Madrid exceeded red clover, Hubam, Grimm and ladino

Common alfalfa, ladino, Grimm and Hubam exceeded red clover

Yield of roots

Madrid, common alfalfa and Grimm exceeded Hubam, ladino and red clover

Total dry matter

Madrid exceeded red clover, Hubam and ladino

Common alfalfa and Grimm exceeded red clover

Nitrogen Yield

Yield of tops

Madrid exceeded red clover and Hubam

Yield of roots

Madrid, Grimm and common alfalfa exceeded ladino, Hubam and red clover

Total nitrogen yield

Madrid, common alfalfa and Grimm exceeded red clover, Hubam and ladino

Percent Nitrogen

Tops

Grimm exceeded Hubam, ladino, Madrid and common alfalfa

Red clover, common alfalfa and Madrid exceeded Hubam and ladino

Roots

Grimm exceeded ladino

In 1952, good stands of all legumes were obtained at all locations, and the pre-emergence application of Dieldrin completely controlled sweetclover weevils. Climatic conditions, both spring and summer, were ideal for the growth of the seedings, and even the unusually dry fall did not seem to markedly affect the legume populations.

The one outstanding legume of the 1952 season was Madrid sweetclover. It was superior to all other legumes with respect to either top or root or total yield of dry matter. At Kanawha, Hubam sweetclover was still in bloom at the time of sampling and thus exhibited a yield of tops as high as that for Madrid; at Marcus, the alfalfas produced a heavy growth which was not significantly different from that of Madrid. The total yield of Madrid varied between 4500 and 6300 pounds of dry matter per acre.

The two alfalfas yielded in the range of from 2200 to over 4000 pounds of dry matter per acre, the highest yields produced at Marcus. They were, for the most part, inferior in yield to Madrid and superior to the other three legumes except at Ames, where ladino produced slightly more dry matter than the alfalfas. Although in a few instances the data indicated one of the two alfalfas superior to the other with respect to yield of tops, roots, or total dry matter, these differences were small and inconsistent.

Ladino clover produced between 2000 and 2900 pounds of total dry matter per acre, of which 250 to 600 pounds were in the roots. These root yields compared favorably with the 300 to 600 pounds of dry matter in medium red clover roots or with the 150 to 600 pounds in Hubam sweetclover roots. Furthermore, the yields of ladino leaves and stolons were either equal or superior to those of the tops of Hubam or red clover, resulting in a total dry matter yield of ladino superior to that of the other two legumes.

The nitrogen percentages of either tops or roots did not vary much among legumes. Tops, with the exception of Madrid sweetclover, were usually higher in nitrogen content than the roots. Due to the flowering habits of Hubam sweetclover, discussed previously,the nitrogen content of that legume was commonly lower than that of the other legumes.

The nitrogen yields, which are a function of both dry matter yields and percent nitrogen, tended to follow the dry matter yields relationships between legumes much more than did the nitrogen percentages. As a result, Madrid sweetclover was the highest nitrogen producer at all locations, containing between 135 and 150 pounds of nitrogen per acre. The alfalfas contained between 60 and 120 pounds of nitrogen per acre, the higher yields being obtained at Marcus. There were no consistent and significant differences between Grimm and southern common alfalfas. Ladino clover also was a high nitrogen producer, its yields varying between 50 and 85 pounds per acre. Medium red clover and Hubam sweetclover generally were lowest in yield. Red clover yielded between 20 and 65 pounds of nitrogen per acre, and Hubam between 30 and 80 pounds. The highest yield from Hubam was attained at Kanawha where the growth was still succulent at the time of sampling.

<u>c. Comparison of legume yields over all locations and years</u>. A resumé of the yield data of the six legumes is presented in Table 14. The data indicate in a general way the gross relationships among the legumes in dry matter and nitrogen yields. These figures, however, are only to be used as a general indicator of the average level obtained in the experiments and it must be recalled that they are averages of yields obtained under widely divergent environmental conditions.

The lack of disease and insect pest control in 1951 resulted in abnormally poor yields of alfalfas and sweetclovers: less than one-half ton of dry matter and less than 30 pounds of nitrogen per acre. Medium red and ladino clovers, however, produced between one and one and a half tons of dry matter per acre of tops and roots, equivalent to between 64 and 85 pounds of nitrogen per acre.

The situation was quite different in 1952 when no pronounced adverse conditions affected the legumes. Madrid sweetclover under these conditions yielded over two and a half tons of dry matter per acre containing on the average 140 pounds of nitrogen. Grimm and southern common alfalfas produced one and a half ton of dry matter, yielding over 80 pounds of nitrogen. Although both ladino clover and Hubam sweetclover yielded approximately one and a quarter ton of dry matter per acre, the former contained almost 75 pounds of nitrogen and

Table 14. Yearly mean yields of dry matter and nitrogen in pounds per acre of legumes grown at the four locations in 1951 and 1952

		Grimm Alfalfa	Southern Common Alfalfa	Madrid Sweet-clover	Hubam Sweet-clover	Medium Red Clover	Ladino Clover
1951							
Dry matter yield	Tops	628	710	459	222	1602	2261
	Roots	362	246	357	38	623	580
	Tops + roots	990	956	816	260	2225	2841
Nitrogen yield	Tops	20.5	23.1	13.8	5.5	47.5	71.6
	Roots	10.5	6.4	9.8	.7	16.5	14.0
	Tops + roots	31.0	29.5	23.6	6.2	64.0	85.6
1952							
Dry matter yield	Tops	1695	1847	3127	2137	1208	2171
	Roots	1270	1174	2022	335	459	435
	Tops + roots	2965	3021	5149	2472	1667	2606
Nitrogen yield	Tops	53.9	55.2	80.0	46.7	37.5	64.2
	Roots	33.5	26.9	60.9	7.4	10.6	9.8
	Tops + roots	87.4	82.1	140.9	54.1	48.1	74.0

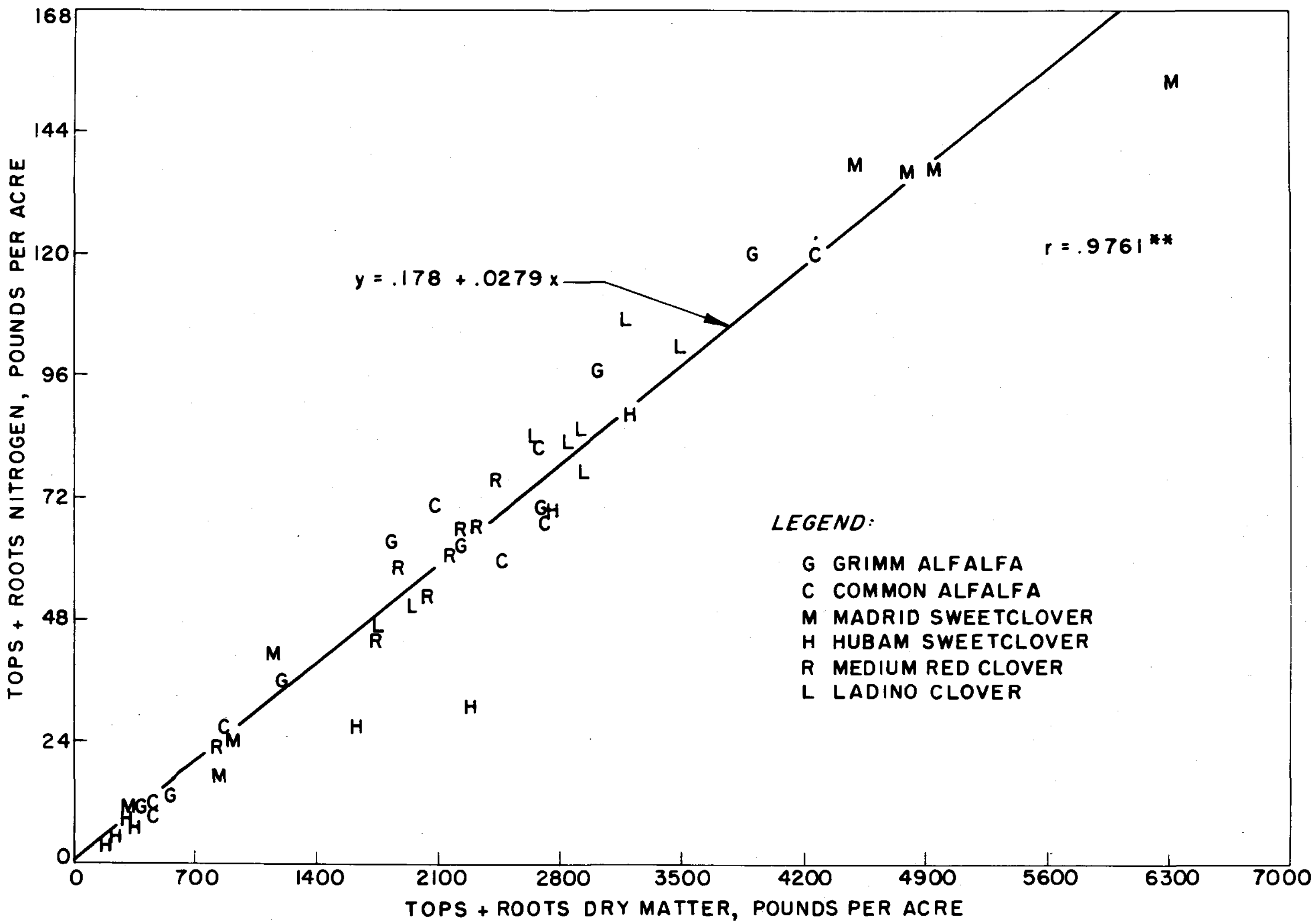
the latter only 54 pounds per acre. Finally, medium red clover produced a little over three quarters of a ton of dry matter per acre, equivalent to slightly less than 50 pounds of nitrogen.

d. Relationships between dry matter and nitrogen yields. The relationship between total dry matter production and total nitrogen yield is presented graphically in Fig. 6. Each point, represented by the appropriate symbol for a particular legume, refers to the mean yield of dry matter and nitrogen of that legume at one location and one season. In other words, since there were four experimental sites in each of two years, each legume was represented eight times on the graph. The correlation coefficient, $r = .976$, which was significant at the 1% level of probability, and the regression equation, $y = .178 + .0279\ x$, were calculated from these forty-eight sets of means.

The relationship between dry matter yield of the tops alone and the total nitrogen yield in the tops and roots was calculated in a similar way (Fig. 7). In this instance, the correlation $r = .936$ was also significant at the 1% level of probability, and the calculated regression equation was $y = .928 + .0396\ x$. A part of the variability responsible for the scatter evident in this graph was due to Hubam sweetclover. These variations were probably due to the stage of growth at which the samples were obtained.

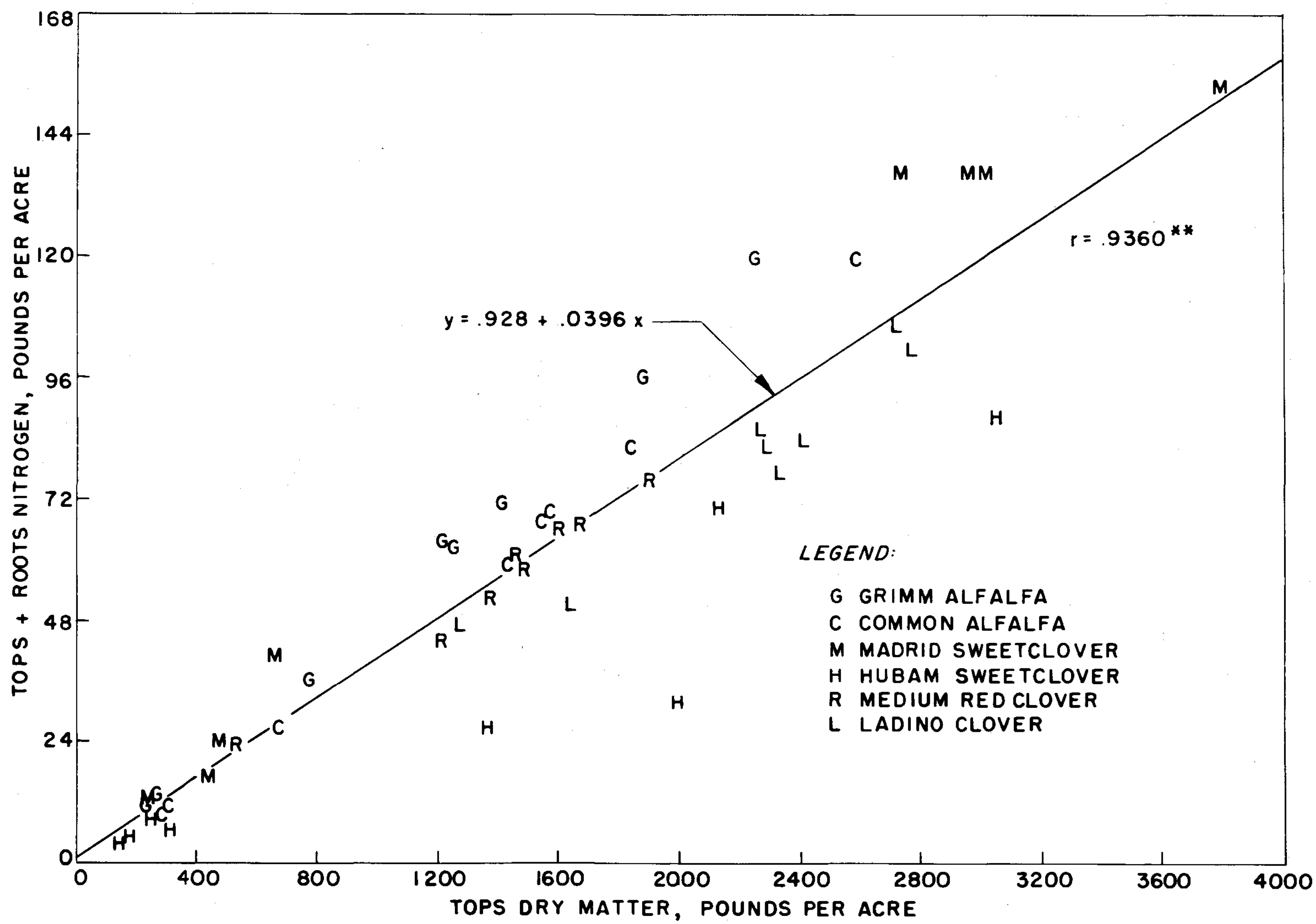
e. Top-root ratios. Analysis of variance of the top-root ratios presented in Tables 6 through 13 indicated, in all cases, that the variation due to legumes was significant at the 1% level when tested with appropriate error mean square on a single location basis for each year.

Fig. 6. Relationship between total dry matter yield and total nitrogen yield, 1951 and 1952



TOPS + ROOTS NITROGEN, POUNDS PER ACRE
0
24
48
72
96
120
144
168
TOPS + ROOTS DRY MATTER, POUNDS PER ACRE
0
700
1400
2100
2800
3500
4200
4900
5600
6300
7000
y = .178 + .0279 x
r = .9761**
LEGEND:
G GRIMM ALFALFA
C COMMON ALFALFA
M MADRID SWEETCLOVER
H HUBAM SWEETCLOVER
R MEDIUM RED CLOVER
L LADINO CLOVER

Fig. 7. Relationship between yield of dry matter in the tops and total nitrogen yield, 1951 and 1952


TOPS + ROOTS NITROGEN, POUNDS PER ACRE
TOPS DRY MATTER, POUNDS PER ACRE
0
24
48
72
96
120
144
168
400
800
1200
1600
2000
2400
2800
3200
3600
4000
y = .928 + .0396 x
r = .9360**
LEGEND:
G GRIMM ALFALFA
C COMMON ALFALFA
M MADRID SWEETCLOVER
H HUBAM SWEETCLOVER
R MEDIUM RED CLOVER
L LADINO CLOVER

However, the greatest part of this variation was due to the high top-root ratios of Hubam sweetclover and ladino clover. The differences among the other legumes were not statistically significant.

Averages of top-root ratios for both dry matter and nitrogen yields over both years and for the four locations are presented in Table 15.

Table 15. Mean top-root ratios of dry matter and nitrogen for legumes grown at the four locations in 1951 and 1952

	Grimm Alfalfa	Southern Common Alfalfa	Madrid Sweet-clover	Hubam Sweet-clover	Medium Red Clover	Ladino Clover
Dry matter	1.52	2.23	1.72	7.99	2.67	4.56
Nitrogen	1.76	3.02	1.69	13.27	3.27	6.39

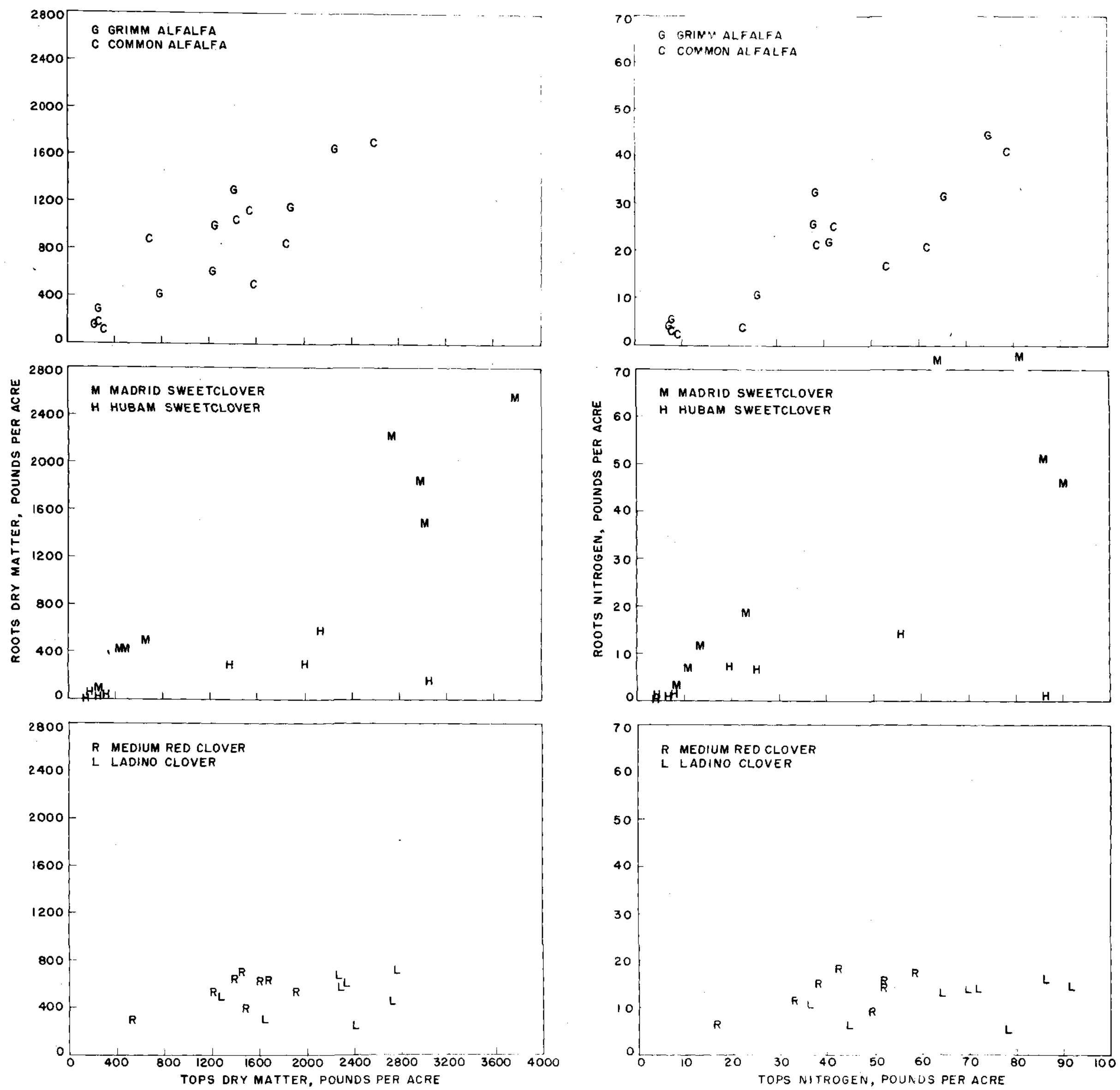
Since each one of these values is the arithmetic average of eighty-six individual observations, and since top-root ratios are notably sensitive to environmental conditions, considerable caution need be exercised in interpreting their meaning. However, the broad variations in ratios among legumes are of some interest. Madrid sweetclover was the closest to unity, followed at a slightly higher value by the alfalfas, thus indicating that the subterranean portions of the plants contributed a substantial part of either dry matter or nitrogen yield. The ratios for medium red clover were larger than those for alfalfa, and in turn were smaller than those for ladino, reflecting the smaller root growth of these legumes with respect to their aerial development. Finally, Hubam sweetclover was much higher than any of the other legumes in top-root ratios. The ratios with respect to nitrogen yield were in nearly all cases superior to those for dry matter yield, pointing out the greater nitrogen content of the tops. The notable exception to this was Madrid sweetclover which had as high a nitrogen yield top-root ratio as that for dry matter yield.

The top-root ratios are presented in a somewhat different manner in Fig. 8. In this figure, the yields of dry matter or nitrogen in the tops were plotted separately for the alfalfas, sweetclover and the two true clovers against the same characters as measured in the roots. Each point in this case represents a mean of the values obtained at a specific location in one of the two years.

The wide differences in yields of alfalfas and sweetclovers between seasons caused a wide scatter of points with respect to both abscissa and ordinate. It would appear, however, that this scatter was not particular to either top or root yields. In other words, top yields of from a few to 3000 or more pounds dry matter per acre, or of from a few to 80 or more pounds of nitrogen per acre, were accompanied throughout the range by proportionately uniform increases in dry matter or nitrogen yields of the roots.

The data for ladino and medium red clovers indicated a somewhat different relationship. There did not seem to be an increase in the yield of roots for either dry matter or nitrogen yield as the top yields were increased. It is quite possible, however, that the absence of a wide range of yields over locations and years for these legumes may have masked an existing relationship.

Fig. 8. Relationship between top and root yields of dry matter and nitrogen


G GRIMM ALFALFA
C COMMON ALFALFA
M MADRID SWEETCLOVER
H HUBAM SWEETCLOVER
R MEDIUM RED CLOVER
L LADINO CLOVER
ROOTS DRY MATTER, POUNDS PER ACRE
ROOTS NITROGEN, POUNDS PER ACRE
TOPS DRY MATTER, POUNDS PER ACRE
TOPS NITROGEN, POUNDS PER ACRE

f. Effect of mowing on seeding-year fall growth. As previously mentioned, two of the four replications at Kanawha were inadvertently mowed on July 24, 1952. The yields of dry matter and nitrogen, nitrogen percentages and top-root ratios as affected by this close clipping are presented in Table 16.

Mowing drastically reduced the dry matter and nitrogen yields of Madrid sweetclover, and this effect was more pronounced on the roots than on the tops. Simultaneously, the nitrogen content of roots was decreased by clipping, whereas no effect was measured on the nitrogen percentage in tops. Yields of dry matter and nitrogen of Hubam tops also were markedly decreased following mowing, although the small root system apparently was not affected.

The other four legumes were altered in a completely different way. Mowing did not appreciably modify nitrogen percentages or top-root ratios, but it did increase dry matter and nitrogen yields. Ladino clover was most affected by this treatment, but medium red clover and the alfalfas also were measurably increased as to yield as a result of July clipping.

Table 16. Yields of dry matter and nitrogen in pounds per acre, nitrogen percentages, and top-root ratios of legumes grown at Kanawha in 1952, as affected by July mowing
(Means of two replications, four quadrats per plot)

		Grimm Alfalfa	Southern Common Alfalfa	Madrid Sweet-Clover	Hubam Sweet-clover	Medium Red Clover	Ladino Clover
Dry Matter Yield							
Tops	Mowed[1]	2059	2107	587	1312	2177	3601
	Not mowed	1878	1841	3014	3051	1483	2417
Roots	Mowed	1424	912	288	133	491	400
	Not mowed	1152	843	1488	149	390	251
Tops + Roots	Mowed	3483	3019	875	1445	2668	4001
	Not mowed	3030	2684	4502	3200	1873	2668
Percent Nitrogen							
Tops	Mowed	3.48	3.15	2.92	2.73	3.42	3.09
	Not mowed	3.48	3.34	2.85	2.83	3.36	3.23
Roots	Mowed	2.62	2.12	2.87	1.63	2.15	2.08
	Not mowed	2.75	2.44	3.42	1.14	2.35	2.30
Nitrogen Yield							
Tops	Mowed	71.6	66.4	17.1	35.6	72.9	111.8
	Not mowed	65.2	61.6	85.8	86.4	49.4	78.1
Roots	Mowed	37.2	19.4	8.2	2.2	10.5	8.3
	Not mowed	31.7	20.4	50.8	1.7	9.2	5.8
Tops + Roots	Mowed	108.8	85.8	25.3	37.8	83.4	120.1
	Not mowed	96.9	82.0	136.6	88.1	58.6	83.9
Tops/Roots							
Dry matter	Mowed	1.45	2.33	1.85	10.10	4.72	9.12
	Not mowed	1.62	2.20	2.10	17.83	3.83	10.02
Nitrogen	Mowed	1.92	3.42	2.08	16.45	6.92	13.40
	Not mowed	2.04	3.00	1.69	51.78	5.46	13.58

[1]Mowed at 2" height on July 24.

g. Relative efficiencies of legume quadrat sampling. Partial analyses of variance for the dry yields of tops and roots of legumes grown at Ames, Clarinda and Marcus in 1952 are presented in Table 17. The 1951 data were not used because of the thin stands obtained for four out of the six legumes in that season. The 1952 Kanawha data were not utilized because of the disturbing effects of clipping in that year.

Preliminary calculations indicated that relative efficiencies did not vary appreciably for top or root sampling from location to location. Pooled error mean squares, therefore, were used for the computation of the relative efficiencies tabulated in Table 17. Relative efficiency of an experimental design with respect to another is defined as equal to

$$\frac{1/V_a}{1/V_b} ,$$

where V_a is the variance of a treatment mean in the design which is being compared to the one (the design actually used) where the variance of a treatment mean is equal to V_b. The variance of a treatment mean, $\sigma^2_{\bar{x}}$ is defined as

$$\sigma^2_{\bar{x}} = \frac{\sigma^2_s}{r\,q} + \frac{\sigma^2_e}{r} ,$$

where σ^2_s and σ^2_e are estimates of sample (quadrat) variance and error variance respectively, r is the number of replications and q the number of quadrats or samples per plot.

The calculated relative efficiencies indicated that less information would be obtained through either decreasing the number of quadrats per

Table 17. Partial analyses of variance and relative efficiencies of sampling with respect to top and root dry matter yields of legumes grown at three locations in 1952

Source of Variation	d.f.	Mean Squares Tops	Roots
Ames			
Replications x Legumes	15	14,581	13,660 **
Quadrats	72	12,836	5,012
Clarinda			
Replications x Legumes	15	61,535 *	26,627
Quadrats	72	32,677	18,050
Marcus			
Replications x Legumes	15	76,805 **	17,087 **
Quadrats	72	19,444	4,618
All locations pooled			
Replications x Legumes	45	50,974 **	19,125 **
Quadrats	216	21,652	9,227

Number of replications	Number of quadrats	Total samples	Relative Efficiencies Tops	Roots	Average
1	16	16	36.7	39.2	38.0
4	1	4	44.0	40.9	42.4
2	8	16	63.5	65.9	64.7
4	2	8	70.2	67.4	68.8
4	3	12	87.6	86.1	86.8
4	4	16	100.0	100.0	100.0
4	6	24	116.5	119.2	117.8
4	8	32	127.0	131.8	129.4
8	2	16	140.4	134.9	137.6
6	4	24	150.0	150.0	150.0
16	1	16	175.9	163.4	169.6
8	4	32	200.0	200.0	200.0

*Significant at the 5% level of probability.

**Significant at the 1% level of probability.

plot in a four replication design, or decreasing the number of replications while increasing the number of quadrats per plot. These statements assumed, however, as do all conclusions derived from calculations of relative efficiencies, that the variances would be the same for the new design as they were for the one that was actually utilized, namely, four replications of a randomized complete block with four quadrats per plot.

Increasing the number of quadrats above four per plot in a design involving four replications would have given up to 30 percent more information with a total number of 32 samples, whereas the use of six replications and four quadrats increased the relative efficiency to 150 percent of the original design. Increasing the number of replications to eight would have doubled the efficiency.

If it is assumed, however, that it would not be possible (because of available time, labor or cost) to harvest more than 16 samples per legume at each location, it is possible to compare the expected relative efficiencies with different combinations of replications and samples. From the data in this study, it would appear that a larger number of replications with fewer samples per plot would have increased the relative efficiency for yields of legume roots and tops.

2. Corn response to nitrogen and green manures

The plant populations, yields of grain and cobs, leaf nitrogen and shelling percentages are presented in Tables 18 through 25. The first four tables include the 1952 data, whereas the second four present the

1953 information. Since sequential range was used to test significant differences among treatment means, no analyses of variance are presented. With each table of means a series of statements are made regarding the statistically significant differences between nitrogen sources as measured by corn response.

Analyses of variance of corn populations on a plot basis indicated no significant differences due to either replications or treatments except at Clarinda in 1953. However, this significant variation was due to a greater uniformity in stand in this experiment than was obtained in any other test. The coefficient of variation for stand was only 3.75 percent. The population, on a single plot basis, ranged between 18,000 and 22,000 stalks per acre. In view of these high populations, it seemed doubtful that differences in stand would affect corn yields.

<u>a. Corn populations, yields and nitrogen contents in 1952.</u> From the analysis of sequential range, the following treatments, applied to corn grown at Ames in 1952, were significantly different at the 5% level:

Shelled corn yields

N_3 exceeded check, common alfalfa, Grimm, Madrid, Hubam, red clover and N_1

Ladino and N_2 exceeded check, common alfalfa, Grimm, Madrid, Hubam and red clover

N_1 exceeded check and common alfalfa

Corn leaf percent nitrogen

N_3 exceeded check, Grimm, Hubam, common alfalfa, Madrid, red clover, N_1, N_2 and ladino

Table 18. Plant populations, yields of grain and cobs, leaf nitrogen and shelling percentages in relation to nitrogen and green manure treatments of corn grown at Ames in 1952 (Means of four replications)

	Grimm Alfalfa	Southern Common Alfalfa	Madrid Sweet-clover	Hubam Sweet-clover	Medium Red Clover	Ladino Clover	Check	N_1	N_2	N_3
Legume nitrogen applied (lbs./A)	11.4	11.5	24.7	7.4	53.2	85.9				
NH_4NO_3 nitrogen applied (lbs./A)								19.8	49.4	111.0
Plant population Thousands per acre	16.6	16.5	15.0	16.0	16.0	15.3	15.6	16.8	16.8	16.5
Shelled corn yield Bushels per acre	60.2	54.8	64.1	64.1	68.8	97.8	51.8	79.5	89.4	107.9
Yield in excess of check	8.4	3.0	12.3	12.3	17.0	46.0		27.7	37.6	56.1
Percent leaf nitrogen	1.79	1.97	2.05	1.93	2.05	2.57	1.73	2.17	2.47	2.88
% leaf nitrogen in excess of check	.06	.24	.32	.20	.32	.84		.44	.74	1.15
Yield of cobs Tons per acre	.32	.28	.33	.34	.35	.46	.29	.38	.44	.55
Shelling percentage	83.7	84.5	84.3	84.2	84.4	85.7	83.4	85.3	85.1	84.6

Ladino exceeded check, Grimm, Hubam, common alfalfa, Madrid, red clover and N_1

N_2 exceeded check, Grimm, Hubam, common alfalfa, Madrid and red clover

Corn cob yields

N_3 exceeded common alfalfa ,check, Grimm, Madrid, Hubam, red clover N_1, N_2 and ladino

N_2 and ladino exceeded common alfalfa, check, Grimm, Madrid, Hubam and red clover

Shelling percentages

Ladino exceeded check

From the analysis of sequential range, the following treatments, applied to corn grown at Clarinda in 1952, were significantly different at the 5% level:

Shelled corn yields

N_3 exceeded check

Corn leaf percent nitrogen

N_3, N_2 and N_1 exceeded check, Madrid, Hubam, common alfalfa and Grimm

N_3 and N_2 exceeded ladino

Corn cob yields

N_3 exceeded Madrid, check, common alfalfa and red clover

Shelling percentages

No treatment mean exceeded any other treatment mean.

Table 19. Plant populations, yields of grain and cobs, leaf nitrogen and shelling percentages in relation to nitrogen and green manure treatments of corn grown at Clarinda in 1952 (Means of four replications)

	Grimm Alfalfa	Southern Common Alfalfa	Madrid Sweet clover	Hubam Sweet clover	Medium Red Clover	Ladino Clover	Check	N_1	N_2	N_3
Legume nitrogen applied (lbs./A)	13.3	10.5	17.4	4.7	60.5	47.4				
NH_4NO_3 nitrogen applied (lbs./A)								22.8	49.1	115.1
Plant population Thousands per acre	16.6	15.8	16.6	17.0	16.6	15.8	15.9	15.2	16.4	17.8
Shelled corn yield Bushels per acre	105.0	95.7	95.5	108.2	105.2	111.5	86.5	104.2	106.0	125.6
Yield in excess of check	18.5	9.2	9.0	21.7	18.7	25.0		17.7	19.5	39.1
Percent nitrogen (leaf)	3.15	3.14	3.08	3.13	3.32	3.20	3.08	3.47	3.54	3.57
% leaf nitrogen in excess of check	.07	.06		.05	.24	.12		.39	.46	.49
Yield of cobs Tons per acre	.42	.35	.34	.41	.38	.43	.34	.40	.42	.50
Shelling percentage	87.6	88.3	88.4	88.0	88.5	88.0	87.5	87.8	87.7	87.6

From the analysis of sequential range, the following treatments, applied to corn grown at Kanawha in 1952, were significantly different at the 5% level:

Shelled corn yields

Common alfalfa exceeded Hubam, check and Madrid

N_3, N_2 and ladino exceeded Hubam and check

Grimm and N_1 exceeded Hubam

Corn leaf percent nitrogen

N_3, N_2, N_1, Grimm, red clover, ladino, common alfalfa and Madrid exceeded Hubam

N_3 and N_2 exceeded check

Corn cob yields

Common alfalfa, N_3, N_2, ladino and Grimm exceeded Hubam

Common alfalfa and N_3 exceeded check

Shelling percentages

No treatment mean exceeded any other treatment mean.

At Marcus in 1951, only three of the four replications of the legumes were sampled. In reporting the response of corn to nitrogen applications, the mean value of these three replications with respect to legume nitrogen plowed under was utilized, but the corn means are based on all four replications.

From the analysis of sequential range, the following treatments, applied to corn grown at Marcus in 1952, were significantly different at the 5% level:

Table 20. Plant populations, yields of grain and cobs, leaf nitrogen and shelling percentages in relation to nitrogen and green manure treatments of corn grown at Kanawha in 1952 (Means of four replications)

	Grimm Alfalfa	Southern Common Alfalfa	Madrid Sweet-clover	Hubam Sweet-clover	Medium Red Clover	Ladino Clover	Check	N_1	N_2	N_3
Legume nitrogen applied (lbs./A)	63.0	69.4	41.3	8.8	75.5	106.8				
NH_4NO_3 nitrogen applied (lbs./A)								21.4	48.1	98.0
Plant population Thousands per acre	16.2	16.4	16.6	16.9	16.4	16.2	16.8	16.2	17.2	16.6
Shelled corn yield Bushels per acre	107.8	122.5	95.2	83.6	103.4	114.2	86.8	107.6	116.2	112.1
Yield in excess of check	21.0	35.7	8.4	- 3.2	16.6	27.4		20.8	29.4	25.3
Percent leaf nitrogen	2.88	2.80	2.70	2.37	2.86	2.85	2.51	2.90	2.94	3.04
% leaf nitrogen in excess of check	.37	.29	.19	- .14	.35	.34		.39	.43	.53
Yield of cobs Tons per acre	.55	.62	.48	.39	.52	.58	.42	.53	.58	.60
Shelling percentage	84.5	84.8	84.7	85.8	84.7	84.6	85.2	85.0	84.8	84.0

Table 21. Plant populations, yields of grain and cobs, leaf nitrogen and shelling percentages in relation to nitrogen and green manure treatments of corn grown at Marcus in 1952 (Means of four replications)

	Grimm Alfalfa	Southern Common Alfalfa	Madrid Sweet-clover	Hubam Sweet-clover	Medium Red Clover	Ladino Clover	Check	N_1	N_2	N_3
Legume nitrogen applied (lbs./A)	36.5	26.4	11.1	4.1	66.9	102.4				
NH_4NO_3 nitrogen applied (lbs./A)								22.6	48.6	97.2
Plant population Thousands per acre	16.9	17.2	16.9	18.0	17.8	17.2	17.1	17.2	17.9	17.5
Shelled corn yield Bushels per acre	102.0	96.3	91.0	114.3	98.2	100.6	102.3	110.9	113.3	116.6
Yield in excess of check	- .3	-6.0	-11.3	12.0	-4.1	-1.7		8.6	11.0	14.3
Percent leaf nitrogen	2.84	2.49	2.61	2.52	2.61	2.71	2.94	2.86	2.97	3.21
% leaf nitrogen in excess of check	-.10	-.45	-.33	-.42	-.33	-.23		-.08	.03	.27
Yield of cobs Tons per acre	.55	.45	.42	.53	.46	.46	.47	.54	.54	.56
Shelling percentage	85.7	85.8	85.9	85.8	85.7	86.1	85.9	85.3	85.4	85.5

Shelled corn yields

N_3 exceeded Madrid and common alfalfa

Hubam, N_2 and N_1 exceeded Madrid

Corn leaf percent nitrogen

N_3 exceeded common alfalfa, Hubam, Madrid, red clover and ladino

N_2 exceeded common alfalfa and Hubam

Check exceeded common alfalfa

Corn cob yields

N_3, Grimm, N_2, N_1 and Hubam exceeded Madrid

Shelling percentages

No treatment mean exceeded any other treatment mean

b. Corn populations, yields and nitrogen contents in 1953. From the analysis of sequential range, the following treatments, applied to corn grown at Ames in 1953, were significantly different at the 5% level:

Shelled corn yields

Madrid exceeded check, N_1, Grimm, Hubam, red clover and common alfalfa

N_3 exceeded check, N_1, Grimm and Hubam

N_2 and ladino exceeded check and N_1

Red clover and common alfalfa exceeded check

Corn leaf percent nitrogen

N_3 exceeded check, Grimm, red clover, common alfalfa, Hubam, ladino, N_1 and N_2

Madrid exceeded check, Grimm, red clover, common alfalfa and Hubam

N_2, N_1 and ladino exceeded check and Grimm

Hubam, common alfalfa and red clover exceeded check

Table 22. Plant populations, yields of grain and cobs, leaf nitrogen and shelling percentages in relation to nitrogen and green manure treatments of corn grown at Ames in 1953 (Means of four replications)

	Grimm Alfalfa	Southern Common Alfalfa	Madrid Sweet-clover	Hubam Sweet-clover	Medium Red Clover	Ladino Clover	Check	N_1	N_2	N_3
Legume nitrogen applied (lbs./A)	63.2	67.3	137.0	26.9	44.5	83.6				
NH_4NO_3 nitrogen applied (lbs./A)								25.7	51.4	82.6
Plant population Thousands per acre	18.2	18.6	17.4	18.3	18.6	18.7	18.5	18.3	18.7	17.9
Shelled corn yield Bushels per acre	62.6	72.4	93.2	63.6	70.0	82.4	50.1	55.5	76.9	87.9
Yield in excess of check	12.5	22.3	43.1	13.5	19.9	32.3		5.4	26.8	37.8
Percent leaf nitrogen	2.25	2.46	2.89	2.52	2.44	2.64	2.04	2.64	2.77	3.12
% leaf nitrogen in excess of check	.21	.42	.85	.48	.40	.60		.64	.73	1.08
Yield of cobs Tons per acre	.40	.44	.54	.40	.42	.49	.33	.38	.49	.56
Shelling percentage	81.4	82.1	82.9	81.5	82.1	82.4	80.7	80.2	81.4	81.5

Corn cob yields

N_3 and Madrid exceeded check, N_1, Grimm, Hubam, red clover and common alfalfa

N_2, ladino and common alfalfa exceeded check

Shelling percentages

Madrid exceeded N_1 and check

Ladino exceeded N_1

From the analysis of sequential range, the following treatments, applied to corn grown at Clarinda in 1953, were significantly different at the 5% level:

Shelled corn yields

Madrid, N_3, N_2, red clover, ladino, Grimm, common alfalfa, Hubam and N_1 exceeded check

Corn leaf percent nitrogen

Madrid, N_3, N_2, N_1, common alfalfa, red clover, ladino, Grimm and Hubam exceeded check

Madrid, N_3 and N_2 exceeded Hubam

Corn cob yields

N_3, N_2, Madrid, red clover, Grimm, ladino, common alfalfa, Hubam and N_1 exceeded check

N_2 exceeded N_1, common alfalfa and Hubam

Shelling percentages

Madrid exceeded check

In view of the unequal effects of clipping on development and nitrogen content of the legumes grown at Kanawha in 1952 (Table 16), only the data on corn grown in 1953 on the plots not mowed the previous year are presented in Table 24. From the analysis of sequential range, the following treatments were significantly different at the 5% level:

Shelled corn yields

N_3, Grimm, common alfalfa, ladino, Madrid, N_2 and red clover exceeded check

N_3 exceeded N_2

Corn leaf percent nitrogen

No treatment mean exceeded any other treatment mean

Corn cob yields

N_3, Grimm, common alfalfa, Madrid, N_2, ladino and red clover exceeded check

N_3 exceeded N_1

Shelling percentages

No treatment mean exceeded any other treatment mean

Table 23. Plant populations, yields of grain and cobs, leaf nitrogen and shelling percentages in relation to nitrogen and green manure treatments of corn grown at Clarinda in 1953 (Means of four replications)

	Grimm Alfalfa	Southern Common Alfalfa	Madrid Sweet-clover	Hubam Sweet-clover	Medium Red Clover	Ladino Clover	Check	N_1	N_2	N_3
Legume nitrogen applied (lbs./A)	70.4	59.6	153.6	31.7	23.2	50.9				
NH_4NO_3 nitrogen applied (lbs./A)								27.4	54.9	82.6
Plant population Thousands per acre	20.0	18.9	18.5	19.2	20.7	19.0	19.9	18.8	20.6	19.6
Shelled corn yield Bushels per acre	72.4	64.4	86.6	64.3	78.8	73.2	40.3	59.9	86.0	83.0
Yield in excess of check	32.1	24.1	46.3	24.0	38.5	32.9		19.6	45.7	42.7
Percent leaf nitrogen	2.49	2.60	2.90	2.30	2.55	2.53	1.95	2.62	2.86	2.90
% leaf nitrogen in excess of check	.54	.65	.95	.35	.60	.58		.67	.91	.95
Yield of cobs Tons per acre	.44	.40	.51	.40	.47	.44	.27	.40	.52	.50
Shelling percentage	82.0	81.6	82.7	81.6	82.3	82.2	79.9	80.7	82.2	81.8

Table 24. Plant populations, yields of grain and cobs, leaf nitrogen and shelling percentages in relation to nitrogen and green manure treatments of corn grown at Kanawha in 1953 (Means of two replications)

	Grimm Alfalfa	Southern Common Alfalfa	Madrid Sweet-clover	Hubam Sweet-clover	Medium Red Clover	Ladino Clover	Check	N_1	N_2	N_3
Legume nitrogen applied (lbs./A)	96.9	82.0	136.6	88.1	58.5	83.9				
NH_4NO_3 nitrogen applied (lbs./A)								27.0	54.0	79.7
Plant population Thousands per acre	18.7	19.0	18.2	18.6	18.8	18.4	18.6	19.2	18.8	18.4
Shelled corn yield Bushels per acre	68.5	65.6	64.4	55.4	62.0	64.6	41.4	50.6	63.0	73.7
Yield in excess of check	27.1	24.2	23.0	14.0	20.6	23.2		9.2	21.6	32.3
Percent leaf nitrogen	3.22	3.78	3.53	3.10	3.28	3.35	2.85	3.38	3.65	3.54
% leaf nitrogen in excess of check	.37	.93	.68	.25	.43	.50		.53	.80	.69
Yield of cobs Tons per acre	.33	.32	.32	.28	.31	.31	.22	.26	.31	.36
Shelling percentage	85.3	85.2	85.1	84.7	85.0	85.3	84.2	84.4	84.9	85.2

Table 25. Plant populations, yields of grain and cobs, leaf nitrogen and shelling percentages in relation to nitrogen and green manure treatments of corn grown at Marcus in 1953 (Means of four replications)

	Grimm Alfalfa	Southern Common Alfalfa	Madrid Sweet-clover	Hubam Sweet-clover	Medium Red Clover	Ladino Clover	Check	N_1	N_2	N_3
Legume nitrogen applied (lbs./A)	119.1	119.5	136.3	69.8	66.3	77.4				
NH_4NO_3 nitrogen applied (lbs./A)	12.4	12.4	12.4	12.4	12.4	12.4	12.4	39.3	66.2	95.7
Plant population Thousands per acre	21.0	20.4	20.1	19.8	21.6	19.4	19.6	19.9	19.6	19.4
Shelled corn yield Bushels per acre	116.9	112.1	107.4	112.4	113.6	118.1	112.0	117.8	117.7	114.2
Yield in excess of check	4.9	0.1	-4.6	0.4	1.6	6.1		5.8	5.7	2.2
Percent leaf nitrogen	3.06	3.24	3.02	3.00	3.11	3.17	2.90	3.34	3.25	3.33
% leaf nitrogen in excess of check	.16	.34	.12	.10	.21	.27		.44	.35	.43
Yield of cobs Tons per acre	.65	.61	.62	.62	.64	.64	.59	.64	.63	.61
Shelling percentage	83.5	83.6	82.8	83.5	83.2	83.7	84.1	83.7	83.9	84.0

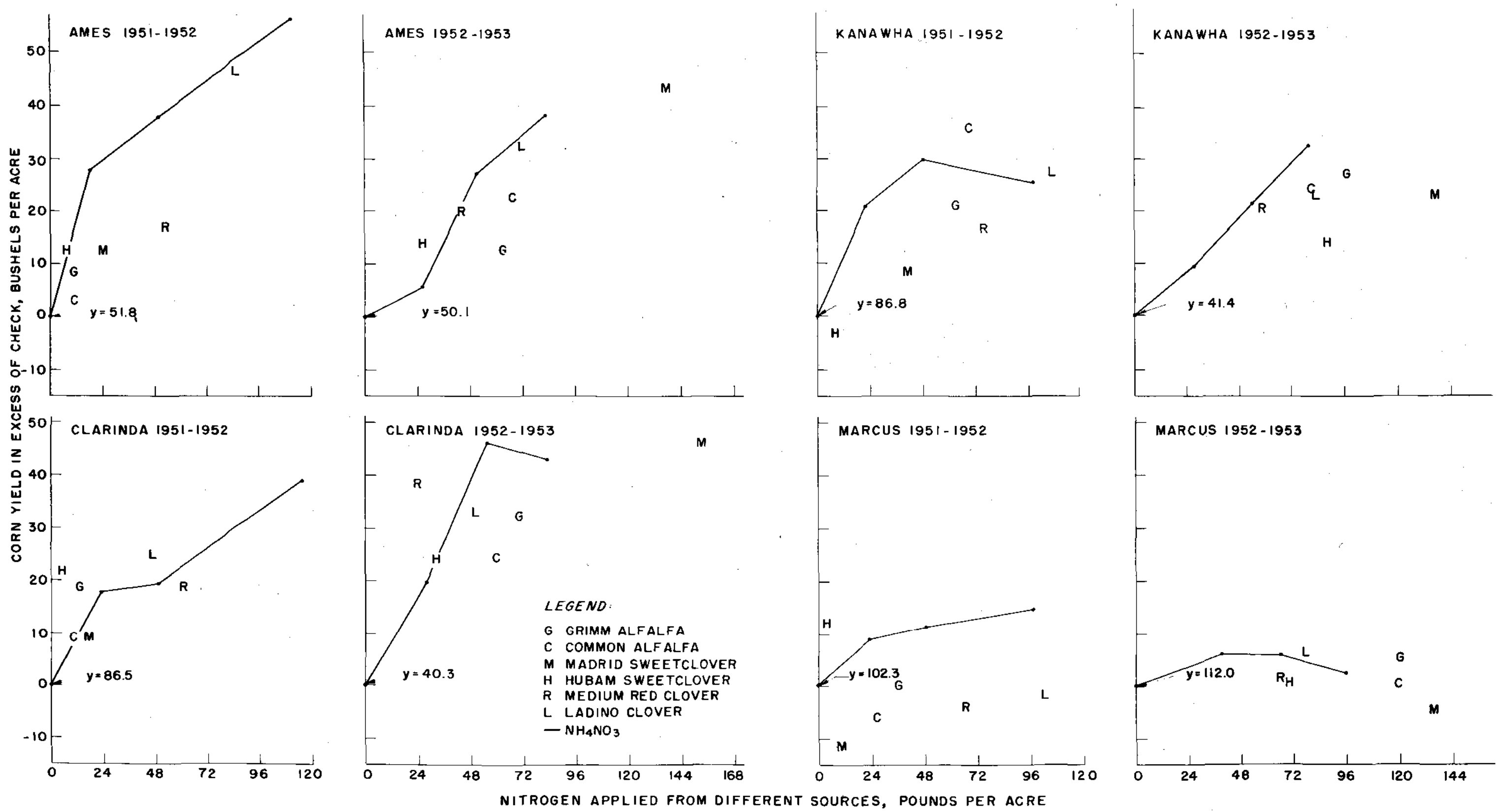
The analysis of sequential range for the data pertaining to corn grown at Marcus in 1953 indicated that treatments were not significantly different with respect to shelled corn yields, corn leaf percent nitrogen or corn cob yields. However, as regards shelling percentage, N_3 and check exceeded Madrid sweetclover at the 5% level of probability.

c. Summary and graphical representation of corn data. Examination of the data for corn cob yields and shelling percentages indicated that in general the nitrogen and green manure treatments had little, if any, effect on these two characters. The greatest range in shelling percentage in any one experiment was only 2.8 percent, representing a variation of approximately 3.5 percent of the general mean. In view of this narrow range and small experimental error for this character, it would appear that any differences among treatments for shelling percentage would have little agronomic meaning. This statement is further substantiated by the fact that whichever treatments were determined to be significantly different as to cob yields also were different as to shelled corn yields, although generally fewer treatments were different for cob than for grain yield.

The yields of shelled corn ranged from 40.3 to as high as 125.6 bushels per acre (on a 1.4 percent moisture basis). In view of the main objective of this study, i.e., the comparison of leguminous green manures among each other and with a source of inorganic nitrogen as to their effect on corn, a graphical representation of the yields of corn in excess of check plotted against nitrogen applied from different sources is presented in Fig. 9.

Each graph in this figure is accompanied by the mean yield of the check in bushels per acre. These check yields ranged from 40.3 at Clarinda-1953 to 112.0 bushels at Marcus-1953, and depended upon both location and year. The mean yields in excess of check for treatments N_1,

Fig. 9. Relationship between nitrogen applied from different sources and yields of shelled corn in excess of check at four locations in 1952 and 1953


AMES 1951-1952
y = 51.8
AMES 1952-1953
y = 50.1
KANAWHA 1951-1952
y = 86.8
KANAWHA 1952-1953
y = 41.4
CLARINDA 1951-1952
y = 86.5
CLARINDA 1952-1953
y = 40.3
MARCUS 1951-1952
y = 102.3
MARCUS 1952-1953
y = 112.0
LEGEND:
G GRIMM ALFALFA
C COMMON ALFALFA
M MADRID SWEETCLOVER
H HUBAM SWEETCLOVER
R MEDIUM RED CLOVER
L LADINO CLOVER
— NH_4NO_3
CORN YIELD IN EXCESS OF CHECK, BUSHELS PER ACRE
NITROGEN APPLIED FROM DIFFERENT SOURCES, POUNDS PER ACRE

N_2 and N_3 were connected in the graph among each other and with check by means of straight lines.

The ammonium nitrate response curves resulting from this procedure fell into roughly three categories. In the first one were four curves the base points of which were between 40 and 50 bushels: Clarinda-1953 (40.3), Kanawha-1953 (41.4), Ames-1953 (50.1) and Ames-1952 (51.8). In the second group were Clarinda-1952 (86.5) and Kanawha-1952 (86.8). Finally, the third cluster consisted of Marcus-1952 and 1953, the check yields of which were 102.3 and 112.0 bushels per acre, respectively. As the check yield increased in magnitude, the ostensible slope of these curves decreased, eventually approaching zero, at first in the sections of the curves farthest away from the origin and finally throughout. With the exception of the Marcus experiments, where the check yields were high and where statistical treatment indicated little difference among treatment means, it appeared that nitrogen was limiting throughout the range of nitrogen applications used. However, at five out of the eight experiments, the high rate of nitrogen application in the form of ammonium nitrate was not high enough to reach the level where some other condition or factor would have been the chief limiting factor to corn yield.

The corn yields from green manure plots, when plotted against the total nitrogen contributed by each legume, varied according to the year, the location and the species involved. Most points were reasonably close to, and below, the ammonium nitrate response curve, indicating that, pound for pound of applied nitrogen, the legume nitrogen resulted in a lower yield of corn than did the inorganic fertilizer. In the 1951-1952 series at Ames and Clarinda, the low yields of alfalfas and sweetclovers gave little or no corn response, but 50 to 90 pounds of medium red or ladino clover resulted in corn yields equivalent to those obtained from similar applications of ammonium nitrate. An exception to this statement was the corn yield resulting from plowing under red clover at Ames, in 1951. The 1952 corn yield responses following alfalfa, red or ladino clover were higher at Kanawha than at the two previously-mentioned locations. Ladino produced corn yields equivalent to those resulting from application of approximately 75 pounds of ammonium nitrate nitrogen, while the effect of the other three legumes was equivalent to 25 to 35 pounds of inorganic nitrogen per acre. The lack of response of corn to nitrogen at Marcus in 1952 made the comparison of green manure effects difficult.

In the 1952-1953 series, the good stands and high yields of legumes resulted in generally higher corn yield responses than in the previous series. The very high production of Madrid sweetclover (140 pounds of nitrogen per acre) probably was responsible for its relatively low efficiency when compared to ammonium nitrate as a nitrogen source for corn. The yield increase from Madrid sweetclover nitrogen was similar to that obtained from slightly more than half that amount of inorganic nitrogen. However, the corn response to Madrid sweetclover was still the largest obtained from any legume. The other five legumes at Ames, Clarinda and Marcus were arrayed in such a fashion that neither statistical analysis nor graphical presentation could clearly differentiate between them. Again, at Marcus, the lack of response of corn to nitrogen made the comparison of leguminous green manures difficult.

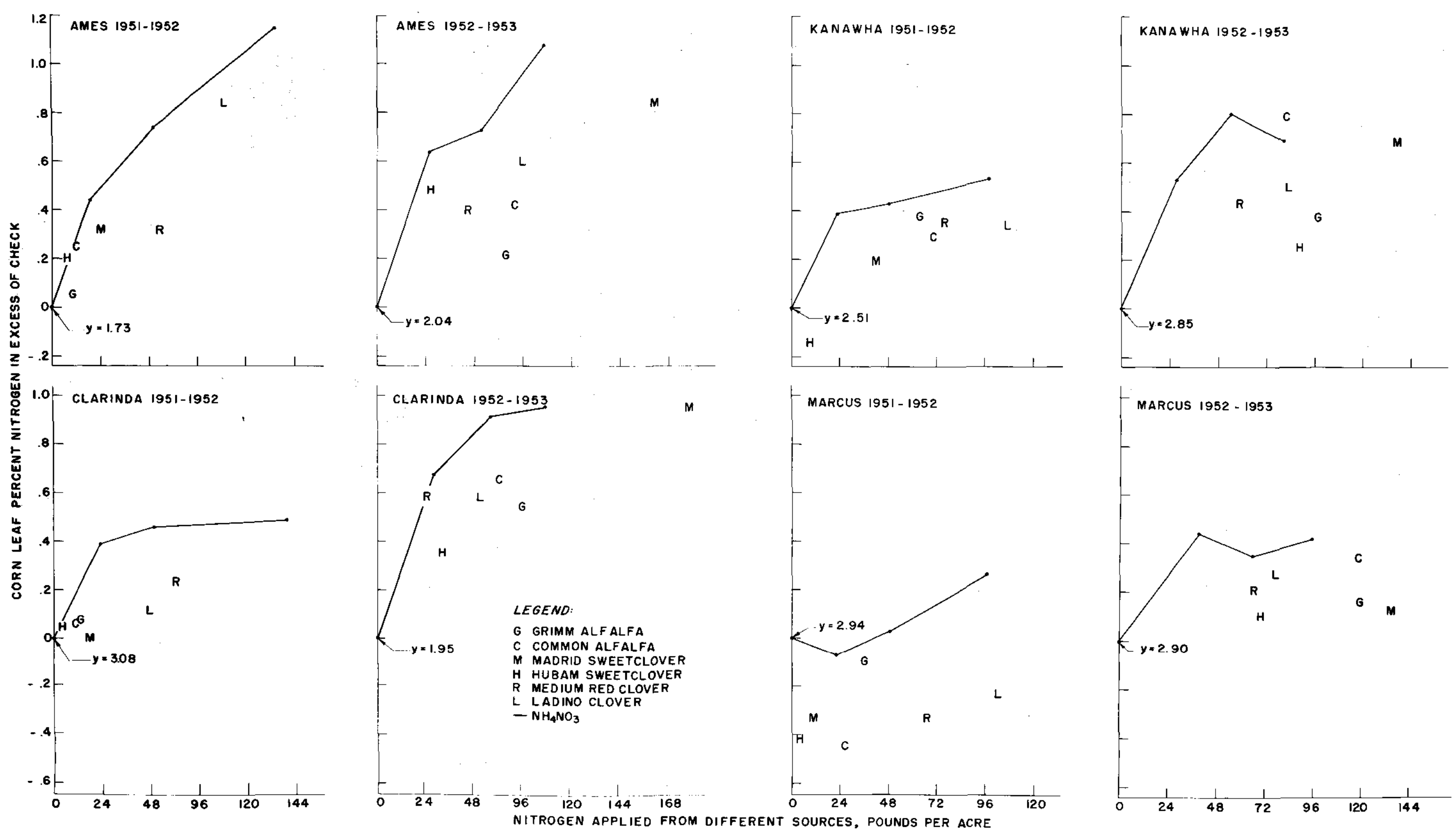
In a few cases the corn response to legume nitrogen was found to be above that of ammonium nitrate. Some of these cases, as for instance with respect to Hubam sweetclover, may be explained on the basis of imperfect estimates of nitrogen contributions from the legume. The few other exceptions to the general rule could not be explained on the basis of the data available in this study. These and other considerations, as well as an attempt to bring data for all locations and years together, will be examined in the discussion of results.

The corn leaf nitrogen percentages ranged from a low of 1.73 to as high as 3.78. These data are presented graphically in Fig. 10, using the same abscissa as in the corn yield graphs and, as ordinate, the percentage nitrogen in excess of that in the check. Each graph also is accompanied by the actual mean leaf nitrogen percentages in the check. The mean nitrogen percentages for check, N_1, N_2 and N_3 are connected by straight lines.

Since one of the primary aims in obtaining corn leaf nitrogen was to provide an additional basis for more fully interpreting the effects of treatments, the corn leaf data will be examined primarily as to their agreement with or departure from the indications obtained from yield measurements.

In general, the ammonium nitrate response curves for corn leaf nitrogen were of the same shape and slope as were the corresponding yield curves, although that for Ames, 1951-1952 was not as steep and

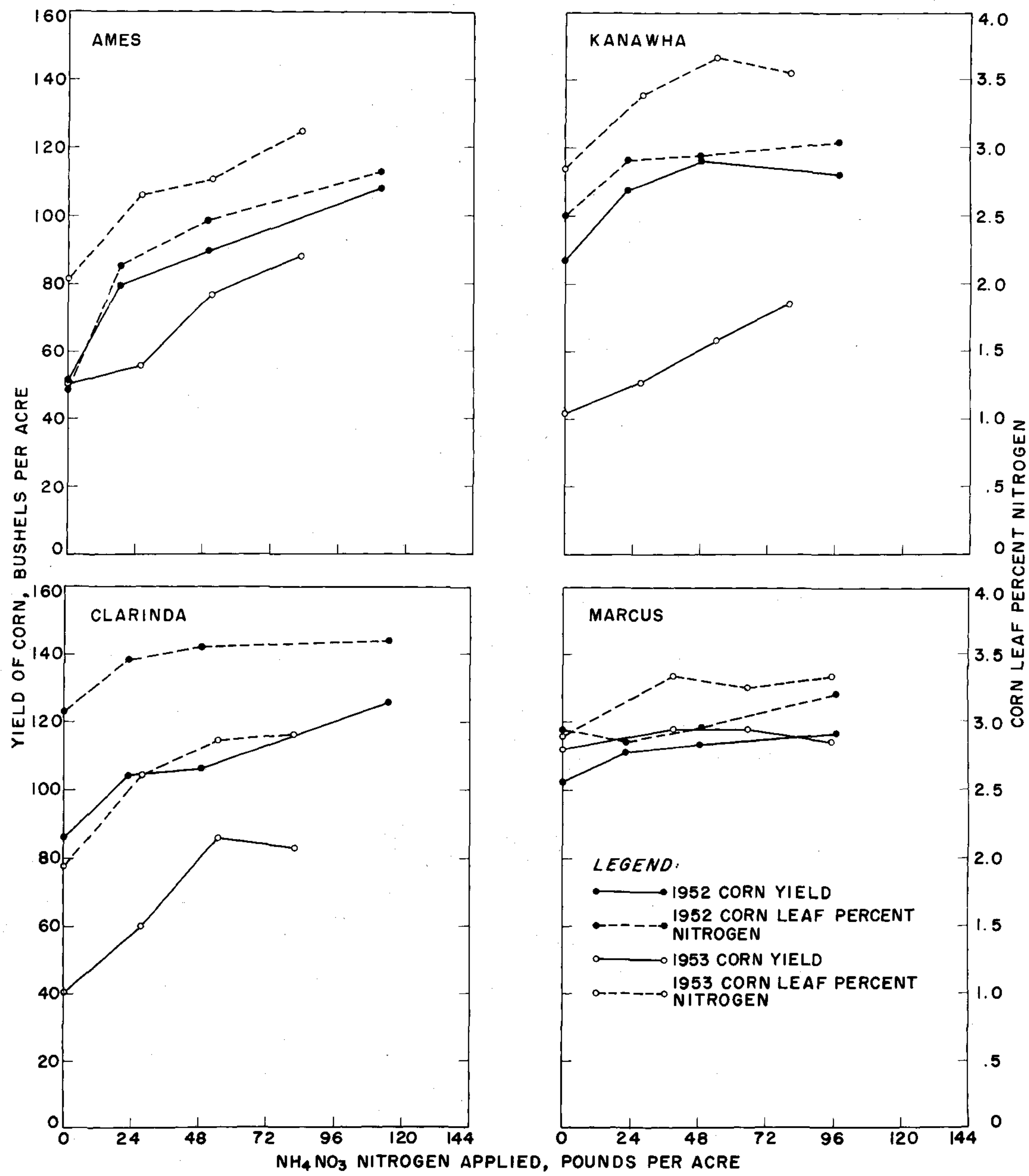
Fig. 10. Relationship between nitrogen applied from different sources and nitrogen percentages in corn leaves in excess of check at four locations in 1952 and 1953


AMES 1951-1952
AMES 1952-1953
KANAWHA 1951-1952
KANAWHA 1952-1953
CLARINDA 1951-1952
CLARINDA 1952-1953
MARCUS 1951-1952
MARCUS 1952-1953
y = 1.73
y = 2.04
y = 2.51
y = 2.85
y = 3.08
y = 1.95
y = 2.94
y = 2.90
CORN LEAF PERCENT NITROGEN IN EXCESS OF CHECK
NITROGEN APPLIED FROM DIFFERENT SOURCES, POUNDS PER ACRE
LEGEND:
G GRIMM ALFALFA
C COMMON ALFALFA
M MADRID SWEETCLOVER
H HUBAM SWEETCLOVER
R MEDIUM RED CLOVER
L LADINO CLOVER
— NH_4NO_3

those for Marcus not as flat. There were only two instances when legume points were above the ammonium nitrate curve. Although there were slight variations in position of legume points when comparing the yield and the leaf nitrogen graphs, there was for the most part a very close similarity between the two. This relationship is presented graphically in Fig. 11 for the check and ammonium nitrate treatments.

In Fig. 11, the ammonium nitrate nitrogen applied is plotted against, on the left-hand ordinate, the actual corn yields and on the right-hand ordinate, the actual corn leaf nitrogen percentages. There was a close relationship between corn yield and leaf percent nitrogen in all cases, as exhibited by the large degree of parallelism between the two curves for these characters for each location and each year. The relative position of the leaf nitrogen curves along the ordinate varied somewhat; this undoubtedly was due primarily to the effect of sampling date which, for practical reasons, could not always be exactly at the time when the plants were in silk and shedding pollen.

Fig. 11. Effect of ammonium nitrate on yields and nitrogen percentages of corn leaves grown at four locations in 1952 and 1953


AMES
KANAWHA
CLARINDA
MARCUS
YIELD OF CORN, BUSHELS PER ACRE
CORN LEAF PERCENT NITROGEN
NH4NO3 NITROGEN APPLIED, POUNDS PER ACRE
LEGEND:
1952 CORN YIELD
1952 CORN LEAF PERCENT NITROGEN
1953 CORN YIELD
1953 CORN LEAF PERCENT NITROGEN
0
20
40
60
80
100
120
140
160
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
24
48
72
96
120
144

B. Preliminary Studies on Other Legumes

1. Preliminary study in 1952

The July notes on height and stand, vigor and yield indices are presented in Table 26. The stands of partridge pea, rush Lespedeza, Alta blue lupine, lappa and large hop clovers and common vetch were very poor and resulted in low yields. Grimm and southern common alfalfas, medium red and ladino clovers, Madrid and Hubam sweetclovers, which were included in this study for comparative purposes, yielded in a similar rank to that observed in the green manure study. Africa, Chilean 21-5 and India alfalfas yielded slightly more than the strain of southern common alfalfa utilized. Floranna sweetclover was slightly more vigorous than Hubam but, like the latter, it had lost its leaves and had dried up by early fall. Outstanding in their appearance when compared at that time with the "standard" legumes were Iowa 6 lespedeza, Dixie crimson clover and hairy vetch. Woods clover, though apparently having made good growth until July, soon thereafter stopped growing, became rank and dried up. Mammoth red clover compared favorably with medium red clover in July, but the latter had surpassed it by fall.

Yields of dry matter and nitrogen, nitrogen percentages and top-root ratios for six of the legumes are presented in Table 27. The total yield of either dry matter or nitrogen of Iowa 6 lespedeza was superior to Madrid sweetclover; however, the top-root ratios for the latter were

Table 26. July stand, vigor and yield indices, and height in inches, of legumes grown at Ames in 1952 (Means of four replications)

	Stand Index	Vigor Index	Height Inches	Yield Index
Partridge pea	3.50	8.00	15.50	3.75
Woods clover	6.00	7.25	12.25	6.00
Bush lespedeza	3.25	4.50	4.50	3.25
Iowa 6 Korean lespedeza	9.00	8.75	8.25	7.75
Italian birdsfoot trefoil	5.00	5.75	5.25	4.75
Alta blue lupine	2.25	6.50	17.00	3.00
Africa alfalfa	7.00	7.50	6.75	7.00
Chilean 21-5 alfalfa	6.50	6.75	7.25	6.75
Grimm alfalfa	6.50	5.50	7.75	5.50
India alfalfa	7.25	6.00	6.75	6.75
Southern common alfalfa	6.75	5.50	6.75	5.00
Floranna white sweetclover	9.25	9.75	21.50	9.25
Hubam white sweetclover	8.25	8.25	18.25	8.00
Madrid yellow sweetclover	9.25	8.50	17.25	7.75
Berseem clover	7.25	7.25	8.75	6.25
Rose clover	6.25	5.75	7.75	5.25
Alsike clover	9.50	8.75	4.75	6.75
Dixie crimson clover	9.50	8.50	10.25	8.00
Lappa clover	3.75	5.25	5.75	3.25
Mammoth red clover	7.75	6.50	5.50	6.75
Medium red clover	8.50	6.50	6.75	6.50
Large hop clover	2.00	4.00	4.50	2.75
Ladino clover	6.75	7.25	4.25	5.75
Persian clover	6.75	6.00	5.50	5.25
Tallarook sub clover	8.50	6.00	3.75	5.50
Common vetch	2.75	4.50	9.25	3.75
Hairy vetch	8.50	9.25	15.75	8.00

Table 27. Yields of dry matter and nitrogen in pounds per acre, nitrogen percentages, and top-root ratios of legumes grown at Ames in 1952 (Means of four replications, two quadrats per plot)

		Iowa 6 Lespedeza	Dixie Crimson Clover	Mammoth Red Clover	Medium Red Clover	Madrid Sweetclover	Hairy Vetch
Dry matter yield	Tops	4306	2353	731	1377	2540	2235
	Roots	464	192	315	496	1462	128
	Tops + roots	4770	2545	1046	1873	4002	2363
Percent nitrogen	Tops	2.77	2.38	3.39	3.06	2.80	3.57
	Roots	2.58	2.04	2.76	2.65	3.00	2.45
Nitrogen yield	Tops	119.0	56.1	24.7	42.0	71.6	78.9
	Roots	11.8	4.0	8.7	13.3	44.4	3.1
	Tops + roots	130.8	60.1	33.4	55.3	116.0	82.0
Tops/Roots	Dry matter	9.28	13.87	2.43	3.00	1.75	19.29
	Nitrogen	10.15	15.84	2.93	3.48	1.62	27.13

approximately 1.7, while ten times as much yield was obtained from the lespedeza tops as from the roots. Hairy vetch and Dixie crimson clover (which by late fall had gone to seed) both yielded one and a quarter tons of dry matter per acre. The crimson clover was lower in nitrogen content, however, and produced only 60 pounds of nitrogen per acre, as compared to 80 for hairy vetch. Both of these legumes were very low in root yields. Mammoth red clover was inferior to medium red clover in both top and root yields, but particularly with respect to aerial portions. Whereas medium red clover produced 1800 pounds of dry matter per acre, equivalent to 55 pounds of nitrogen, mammoth red clover yielded only one half ton of dry matter containing 33 pounds of nitrogen per acre.

Visual comparisons in the fall of root and top growth of some legumes are afforded in Fig. 12 and Fig. 13. The smaller stature of mammoth red and sub clovers with respect to medium red and ladino clovers, respectively, was quite evident. The tallness of Madrid sweetclover was offset by the dense, leafy growth of Iowa 6 lespedeza. The stemminess and small leaf numbers of partridge pea and woods clover were noticeable, while the almost recumbent habit of growth of hairy vetch was further accentuated by its length of stem.

2. Preliminary study in 1953

Yields of dry matter and nitrogen, and nitrogen percentages of seven of the legumes included in this study are presented in Table 28. Due to severe mid-summer and fall drought, only tops were harvested of

Fig. 12. Relative appearance and fall growth of some legumes grown at Ames in 1952

From left to right: Madrid sweetclover, medium red clover, Grimm alfalfa, mammoth red clover, Tallarook sub clover and ladino clover

Fig. 13. Relative appearance and fall growth of some legumes grown at Ames in 1952 (continued)

From left to right: hairy vetch, partridge pea, woods clover, Dixie crimson clover and Iowa 6 lespedeza

Table 28. Yields of dry matter and nitrogen in pounds per acre and nitrogen percentages of tops of legumes grown at Ames in 1953 (Means of four replications, four quadrats per plot)

	Dry Matter Yield	Percent Nitrogen	Nitrogen Yield
Iowa 6 lespedeza	875	1.24	10.7
Southern common alfalfa A	576	1.94	11.2
" " " B	510	2.05	10.6
" " " C	747	2.06	15.5
Mammoth red clover	646	2.34	15.2
Medium red clover	715	2.58	18.6
Hairy vetch	484	2.57	12.6

those legumes having best survived unfavorable growing conditions. The lowest-yielding legume among those harvested was hairy vetch, but two of the southern common alfalfas also produced only approximately one quarter ton of dry matter and ten to twelve pounds of nitrogen per acre. Southern alfalfa C yielded about 200 pounds dry matter and five pounds nitrogen more than the other two strains, indicating that southern alfalfa A, which was used in the green manure study, was not necessarily the highest-producing Southern alfalfa. Mammoth red clover was slightly inferior to medium red clover, and both were exceeded in dry matter production by Iowa 6 lespedeza. At sampling time, however, the lespedeza had dried up, and the ensuing low nitrogen percentage decreased its nitrogen yield to ten pounds per acre.

C. Corn Response and Residual Effects from Freshly-Cut and Other Crop Residues

1. Corn responses

The plant populations, yields of grain and cobs, and leaf nitrogen and shelling percentages are presented in Table 29. Analysis of variance indicated significant differences due to treatment with respect to plant populations. The greater part of this variation was attributable to treatments OH, RC 3 and RC 4, which were significantly lower in stand than the other treatments. Reasons for lower stands in the latter two are obscure, but oat hulls had a visible depressing effect on number and size of corn plants. The oat hull plots were the only ones that required no hoeing throughout the season.

Table 29. Plant populations, yields of grain and cobs, leaf nitrogen and shelling percentages in relation to nitrogen and organic material treatments of corn grown at Ames in 1952 (Means of four replications)

Treatment	Nitrogen Applied (lbs./A)	Plant Populations (M/A)	Shelled Corn Yield (bu./A)	Percent Leaf Nitrogen	Yield Cobs (T/A)	Shelling Percentage
A 1	28.3	16.2	97.3	2.83	.48	85.1
A 2	56.7	14.7	95.2	2.78	.44	85.8
A 3	113.4	15.1	103.6	3.24	.52	84.8
A 4	170.0	15.5	108.0	3.10	.54	84.8
RC 1	34.5	15.7	79.0	2.70	.39	85.0
RC 2	69.1	16.3	82.6	2.60	.41	84.8
RC 3	138.2	13.4	92.4	2.84	.46	84.9
RC 4	207.2	13.8	102.3	3.01	.51	84.9
SB 1	25.5	16.8	70.1	2.46	.35	85.0
SB 2	51.1	16.0	71.1	2.31	.35	84.9
SB 3	102.2	15.4	75.8	2.39	.41	83.7
SB 4	153.2	16.4	63.9	2.49	.34	83.8
OH	228.0	13.9	63.6	2.37	.33	84.2
SB-N3	151.6	16.8	98.1	2.86	.51	84.3
N 1	10.8	16.7	90.4	2.63	.48	85.1
N 2	19.8	16.7	98.0	2.76	.46	84.5
N 3	49.4	17.4	113.2	3.03	.56	84.9
N 4	111.0	16.4	116.8	2.84	.54	85.8
N 5	166.9	16.1	116.5	3.20	.58	84.8
Check	---	16.7	72.8	2.53	.38	84.4

Analysis of variance of shelling percentages indicated no significant differences due to treatments, but there appeared to be a trend toward lower shelling percentages as nitrogen applications and yields were increased. The yield of cobs in general followed very closely the grain yields, though they were somewhat more variable.

From the analysis of sequential range, the following treatments, applied to corn grown at Ames in 1952, were significantly different at the 5% level with respect to shelled corn yield:

N 5, N 4 and N 3 exceeded OH, SB 4, SB 1, SB 2, check, SB 3, RC 1 and RC 2

A 4 exceeded OH, SB 4, SB 1, SB 2, check, SB 3 and RC 1

A 3 and RC 4 exceeded OH, SB 4, SB 1, SB 2, check and SB 3

SB-N3, N 2 and A 1 exceeded OH, SB 4, SB 1 and SB 2

A 2 exceeded OH, SB 4 and SB 1

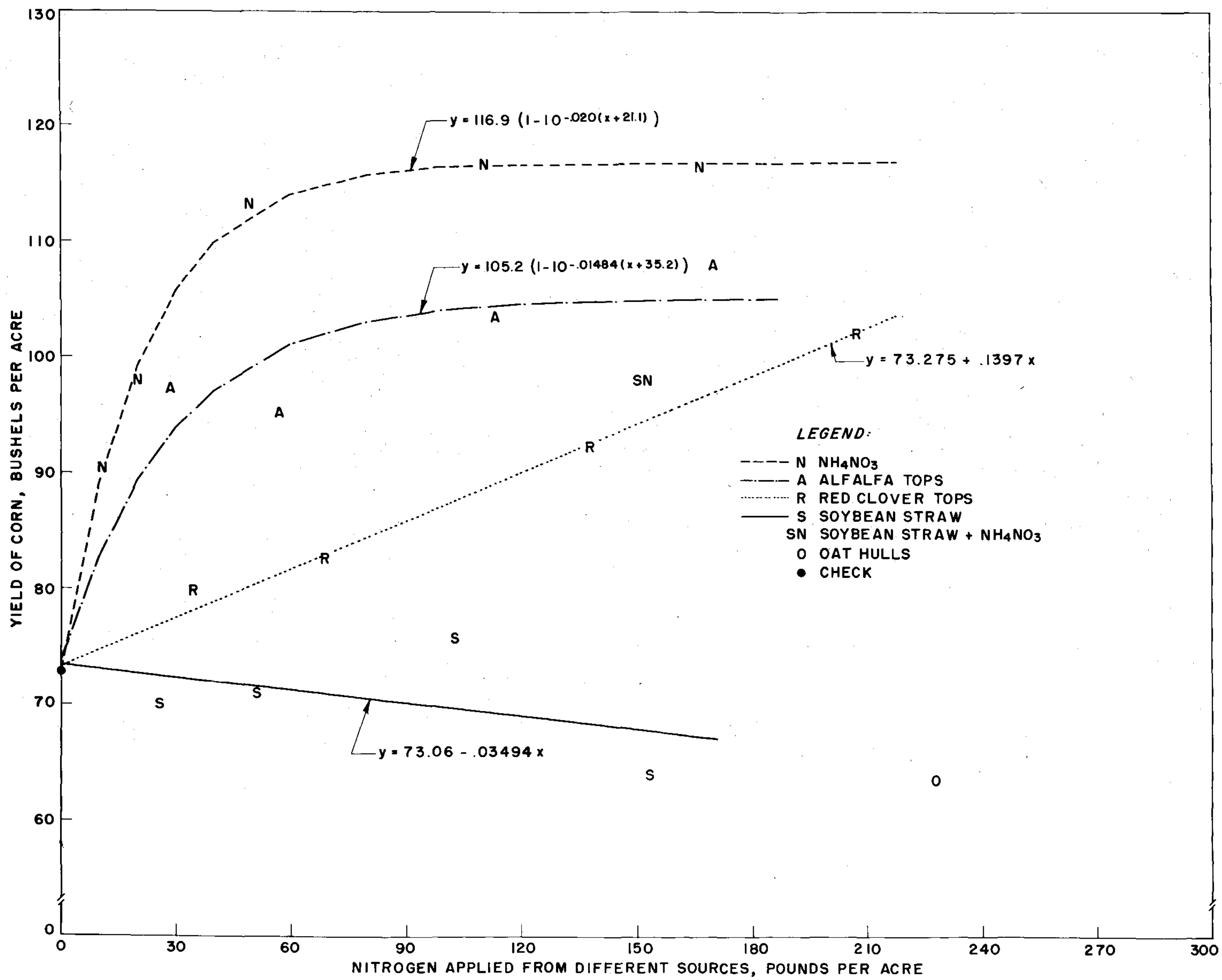
RC 3 and N 1 exceeded OH and SB 4

Graphic representation of the yield data (Fig. 14) more vividly brought out the varying corn yield response to applications of the different nitrogenous materials. Curves were fitted to the data by the method of least squares. In the case of soybean straw and red clover, the closest fits were obtained with straight lines, described by $y = 73.06 - .03494\ x$ and $y = 73.275 + .1397\ x$, respectively.

The nature of the corn response to alfalfa and ammonium nitrate appeared to more closely follow a logarithmic pattern; the data were fitted to a curve of the form

$$\log (A-y) = \log A - c\ (x + b),$$

Fig. 14. Relationship between nitrogen applied from different sources and yield of corn grown at Ames in 1952


YIELD OF CORN, BUSHELS PER ACRE
NITROGEN APPLIED FROM DIFFERENT SOURCES, POUNDS PER ACRE
0
30
60
90
120
150
180
210
240
270
300
60
70
80
90
100
110
120
130
y = 116.9 (1-10^-.020(x+21.1))
y = 105.2 (1-10^-.01484(x+35.2))
y = 73.275 + .1397 x
y = 73.06 - .03494 x
LEGEND:
N NH4NO3
A ALFALFA TOPS
R RED CLOVER TOPS
S SOYBEAN STRAW
SN SOYBEAN STRAW + NH4NO3
O OAT HULLS
● CHECK

where y is the yield associated with the amount b of nitrogen present in the soil or the amount b in the soil plus x units of added nitrogen, A is the maximum yield that can be produced as x approaches infinity, and c is a constant. This function is oftentimes referred to as the Mitscherlich curve, and a method for least squares evaluation has been presented by Eid et al. (24). The best fit with respect to the response of corn to ammonium nitrate was

$$y = 116.9\ (1 - 10^{-.020(x + 21.1)}),$$

whereas the fitted curve for the response to alfalfa was of the form

$$y = 105.2\ (1 - 10^{-.01484(x + 35.2)}).$$

Using the ammonium nitrate response curve as a basis for the evaluation of the effects of the other nitrogen sources on corn yield, it was observed that the inorganic fertilizer was the most effective in increasing production. At low nitrogen applications (below 30 pounds per acre) the difference between ammonium nitrate and alfalfa was not too large. As the nitrogen applied was increased to around 60 pounds, however, the ammonium nitrate resulted in higher yield increases than alfalfa. Above 60 pounds per acre of applied nitrogen, the difference of 12 bushels per acre between ammonium nitrate and alfalfa nitrogen remained relatively constant.

Freshly-cut medium red clover (of higher nitrogen content than alfalfa) was much less efficient than alfalfa or ammonium nitrate in supplying nitrogen to the corn crop. In the range from zero to 60 pounds applied nitrogen, there was a difference in corn yields of almost 20 bushels between red clover and alfalfa, and of over 25 bushels between red clover and ammonium nitrate at a nitrogen application of 65 pounds per acre. Since the curve fitted to the red clover data was a straight line, it tended to intersect the alfalfa curve at higher abscissa values. The reasons for the straight-line relationship obtained were obscure, but the low corn populations obtained at the two high application levels of red clover may have contributed to incomplete utilization of released nitrogen.

Although increments of applied soybean straw required as high as eight tons of dry matter per acre, the yields were roughly similar to those of check or slightly lower. Examination of corn leaf nitrogen percentages indicated no difference between check or any of the soybean straw treatments. The addition of 50 pounds of ammonium nitrate nitrogen to 100 pounds of soybean straw nitrogen (five tons dry matter per acre) resulted in a corn yield intermediate between soybean straw and ammonium nitrate curves. An application of oat hulls decreased yield to ten bushels below that of check.

The corn leaf nitrogen data in essence substantiated the observations made on yield data. Due to differences in maturity of one to two weeks as affected by treatment, some corn plants were sampled at an earlier stage of maturity than others. This fact was reflected in the variations in nitrogen percentages. Nevertheless, tissue sampling indicated that A 3 and A 4, RC 3 and RC 4, and N 3, N 4 and N 5 had higher nitrogen contents than the lower application treatments of each material. It further pointed out little difference among soybean straw treatments and check, and called attention to effects of oat hulls.

Table 30. Pounds of nitrogen per acre recovered in oats grown at Ames in 1953, in relation to nitrogen and organic material treatments on corn grown in 1952

Previous Treatment	Nitrogen Applied to Corn (lbs./A)	Pounds of nitrogen per acre recovered in oats		
		NH_4NO_3 nitrogen applied to oats:		
		None	15 lbs./A	30 lbs./A
A 1	28.3	31.44	38.60	55.79
A 2	56.7	28.60	49.45	67.20
A 3	113.4	33.09	56.57	62.27
A 4	170.0	33.93	48.24	53.52
RC 1	34.5	30.66	41.92	56.00
RC 2	69.1	28.42	46.32	66.36
RC 3	138.2	24.90	44.15	65.07
RC 4	207.2	30.61	46.72	56.52
SB 1	25.5	25.65	43.64	60.83
SB 2	51.1	23.50	36.39	58.08
SB 3	102.2	31.53	46.25	66.36
SB 4	153.2	28.64	39.74	58.90
OH	228	25.02	38.34	54.62
SB-N 3	151.6	34.76	46.19	63.32
N 1	10.8	25.30	33.86	54.16
N 2	19.8	29.50	45.84	60.50
N 3	49.4	27.42	41.42	57.08
N 4	111.0	31.14	45.53	60.84
N 5	166.9	37.72	58.16	67.60
Check	----	25.28	40.48	58.80

Table 31. Analysis of variance of nitrogen recoveries by oats grown at Ames in 1953

Source of Variation	d.f.	Mean Square
Replications	3	793.55 **
Nitrogen treatments on corn	19	199.73 *
Reps. x N treatments on corn	57	112.21
Nitrogen treatments on oats	2	19 020.02 **
Corn treatments x Oats treatments	38	44.24
Pooled error (b)	120	29.13

* Significant at the 5% level of probability

** Significant at the 1% level of probability

Standard errors of difference between:

(1) Two corn treatments means	4.32
(2) Two oats treatments means	.85
(3) Two oats treatments means for one corn treatment	3.82
(4) Two corn treatments means for a given oats treatment	5.33

2. Residual effects

Pounds of nitrogen recovered in oat aerial portions and the analysis of variance of the data are presented in Tables 30 and 31, respectively. Nitrogen treatments on corn (1952) and nitrogen treatments on oats both were significantly different. However, the interaction between these two sources of variation was not significant. In view of the small range of nitrogen recoveries within each oat treatment, and since the corn treatments mean square was barely significant at the 5% level, it would seem that, under the conditions of this experiment, there was little residual effect from previous treatment with either ammonium nitrate or green and mature crop residues.

V. DISCUSSION

During the past few years there has been a greater realization of the need for increased use of nitrogen for maximizing yields and returns from corn. Therefore, it is of paramount importance to determine the most effective and the cheapest source of this element within the framework of sound agricultural practices. It has been well established that either inorganic nitrogen fertilizer or a previous leguminous crop will increase yield of corn, cereal grains and other crops wherever nitrogen is the chief limiting factor in production. Since the primary objective of this investigation was to compare and evaluate different leguminous sources of nitrogen, the total amount of nitrogen contained in these different sources will be examined first.

Review of the literature on total nitrogen yields from different legumes pointed out that highest yields obtained in roots and tops of sweetclovers approached 160 pounds of nitrogen per acre at the end of the seeding year. Most data, however, indicate values closer to approximately 125 or 130 pounds of nitrogen per acre. One-year old alfalfa plants in general produced less than 100 pounds of nitrogen per acre, though occasionally the yield was higher. Red clover nitrogen yields were found by most investigators to be inferior to those of alfalfa, when measurements were obtained in the fall of the seeding year.

Under the conditions of the current study, good stands were obtained in one year, whereas disease and insect pests reduced stands and drastically diminished yields of four of the six legumes the other year.

However, when good stands were secured, the total nitrogen yields closely approximated those found elsewhere by other investigators. In 1952, Madrid sweetclover yielded 135 to 150 pounds of nitrogen per acre and the alfalfas produced from 60 to 100 or more pounds per acre. Although the dry matter yields of ladino clover were not high, the nitrogen production of this legume was very good in both years. In either a cool and moist year or a season characterized by midsummer and fall drought, ladino clover yielded from 70 to over 100 pounds of nitrogen per acre, with the exception of one instance when the yield was only about 50 pounds. Medium red clover was in one test in 1951 superior to ladino, but in general the nitrogen yields of red clover were lower than those of ladino clover, and ranged between 30 and 70 pounds per acre. Although it was unfortunate that Hubam sweetclover could not, in these experiments, be sampled at the time of maximum dry matter and nitrogen yields, its annual growth habit still resulted in relatively low yields which placed it in all cases at the lowest end of the yield distribution.

Analyses for total nitrogen content did not vary greatly among legumes, and it was apparent that the primary factor in determining nitrogen yield actually was the magnitude of the total dry matter yield. The distribution of yield among aerial and subterranean portions agreed substantially with the evidence obtained by other investigators. However, there were indications that the Madrid sweetclover roots were not as high yielding with respect to the tops as has been found by others. This difference may have been caused by the severe midsummer and fall drought in 1952 and which, instead of resulting in deeper and larger root systems, actually may have hindered seedling growth and development. Since this adverse climatic condition existed at all four experimental sites, comparison with less abnormal conditions was not possible.

The question then arises as to whether the yields of roots recorded were actually good estimates of the growth present in the field. The low estimates of variance obtained in the 1952 data would indicate that variation among quadrats and among plots was low, and was equally low for root and top samples. In 1951, however, when stands for four out of six legumes were poor, and when only two quadrats per plot were used, the estimates of variance were larger. Nevertheless, by the methods used it was possible to differentiate legumes with yield differences of 500 or more pounds dry matter per acre. Since in a study of this nature, the objective was to obtain an estimate of gross yield, the failure to measure 100 percent of the roots was of little consequence, and Willard (98) and others (45) have pointed out that the majority of the roots contributing to total weight are recovered by careful, but not necessarily excessive depth of sampling.

The procedure utilized in root washing resulted in roots free of soil material. The soaking-and-sprinkling method reduced the time required for washing by a factor of ten or more when compared to cleaning in running water (28). Davis (18) wrote in 1945 that

> the necessity of the inclusion of these data [weight of roots of green manure crops] in a correct interpretation of the effects of green manure crops is . . . recognized, although

> in some cases results are still published in which comparisons of various crops for green manuring are evaluated from the top growth alone, a procedure that could easily lead to inaccurate conclusions.

Calculations of relative efficiencies of sampling, based upon the data obtained with good stands of legumes, indicate that more information would have been obtained with the same total number of quadrats (16 per legume at each location) if more replications and less quadrats per plot had been used.

Since both root sampling, on the one hand, and total nitrogen analyses, on the other, require a large expenditure of labor, time and money, it would be greatly advantageous to arrive at an estimate of the information obtained from these two processes through other means. The very high correlation obtained between total dry matter yield and total nitrogen yield for all legumes, as well as the fact that the regression equation, for all practical purposes, intersected the ordinate at the origin, indicates that dry matter yield measurements also were good estimates of nitrogen yield of tops and roots.

Although more scatter was evident when total nitrogen yield was plotted against dry matter yield of tops for all legumes, again the correlation coefficient was above .9, and the regression equation intersected the ordinate at the origin. It seems, therefore, that estimates of dry matter yields of legume tops in the fall of the seeding year, when the stems are severed from the roots at the crown, also are reasonably good estimates of nitrogen yields of tops and roots. Further corroboration is necessary, however, to determine whether this relationship holds under widely different environmental conditions and on other soils adapted to good legume growth. In addition, the relationship between yield of tops cut at the crown, and yields of tops cut above-ground (one-or two-inch stubble) needs study. In this general connection, it is encouraging to note that Erdman and Means (26) stated that, by the use of regression "it is possible to predict, with a high order of precision, the amount of nitrogen in the sample from the dry weight of legumes grown in greenhouse sand cultures". These workers obtained correlations of .89 or better for several legumes when comparing dry weight yields and nitrogen recoveries. On the other hand, Willard (99) found correlations of .36 and .59 between dry matter yields of tops and roots of alfalfa and sweetclover, respectively. These low values may have been due to the fact that older plants were used.

In all cases except one in the current investigation, the companion crop, when harvested at maturity, was removed at a height of eight to twelve inches above-ground. Such a treatment, it was felt, would least alter subsequent growth of legumes, and still would be within the bounds of practical agricultural management. Fortuitous July clipping of two replications at Kanawha in 1952, however, brought out the fact that, for some legumes at least, closer combining than was practiced might actually have increased seeding year fall yields of tops and roots. Data obtained by Willard et al. (100) in Ohio and by others in north-eastern United States indicated that this observation was not unique.

Exploratory studies with over two dozen legumes other than the ones included in the major study indicated that some of them should be considered in future evaluations of green manures in the Corn Belt. Korean lespedeza, hairy vetch and crimson clover appeared particularly promising with respect to yield of nitrogen in the fall of the seeding year. Although it was not possible to differentiate between yields of Grimm and southern-grown (Arizona or California) common alfalfa in the major study, additional observations indicated that different strains of southern common alfalfas yielded differently. More extensive evaluation of strains derived from distinct seed sources therefore would be warranted.

Prior to broaching the subject of the utilization of leguminous nitrogen by succeeding crops, it should be pointed out that a survey of literature on this topic yielded little critical information. In addition to the studies reported in the review of literature, the work of van de Goor (67) merits brief mention, although he worked in Java, and with legumes not adapted to north-central United States. He investigated a large number of leguminous green manures in two-year rotations in many locations and utilized as many as seven or eight replications of 10 x 10 or 10 x 15 meter plots.

In interpreting the relative value of the different legumes as sources of nitrogen for corn as a function of the response of the crop to ammonium nitrate, certain difficulties were encountered. At five out of the eight experiments, the point was not reached where some factor other than nitrogen would have been limiting. This probably was due to either one or both of two causes. The first one of these was the failure to apply high enough rates of ammonium nitrate fertilizer. Even though in some instances the amount applied exceeded 100 pounds of nitrogen per acre, maximum yields were not attained. The second reason for the failure of the ammonium nitrate curves to "flatten out" was a direct consequence of the high corn populations (15,000 to 22,000 stalks per acre) that were used. Kohnke and Miles (43) in Indiana and Muhr and Rost (53) in Minnesota, as well as Duncan (21) more recently in Iowa, all have emphasized that maximum yields of corn were obtained under conditions of adequate fertility only when the population exceeded approximately 15,000 plants per acre. Since corn was grown in this study primarily as an indicator crop, and since other factors such as phosphorus and potassium were supplied in abundant quantity, it was felt that only an adequately large corn population could differentiate between nitrogen applications and sources. This purpose was accomplished at all locations except Marcus, where the check yields were superior to 100 bushels per acre. At this point, it might be argued that the removal of the one leaf blade per hill for tissue analysis might have affected treatments differently. However, data by Dungan (22) and Bergeson (8) indicated that the removal of one leaf reduced corn yields only slightly and not significantly.

The second difficulty encountered in the process of estimating the value of the leguminous green manures relative to ammonium nitrate in terms of corn production was the fact that in a substantial number of cases the corn yields from legume plots were either above or beyond (to the right, in Fig. 9) the ammonium nitrate response curves.

The third, and perhaps most delicate problem in the interpretation of corn yield responses to green manure treatments resulted from the fact that the several ammonium nitrate response curves had different slopes. This situation made it difficult to compare green manure treatments to the corresponding inorganic nitrogen treatments at the same, or at least at equivalent, levels of fertilizer nitrogen application.

In an attempt to obviate these obstacles to interpretation of the data, a mathematical artifice was employed. It was noted earlier that, as the yield of the check treatment increased from experiment to experiment, the ostensible slope of the ammonium nitrate response curves decreased. It was then possible, after ranking the eight response curves in order of increasing check yield, to construct a single curve to which each one of the original curves were tangent. In order to accomplish this, the four points making up the curve with the lowest check yield (Clarinda-1953) were fitted to a straight line by least squares method. When considering the next set of data (Kanawha-1953) the check yield, instead of being plotted on abscissa $x = 0$, was plotted at the point where the ordinate value $y = 41.4$ (yield of check) intersected the line previously fitted to the Clarinda-1953 data. The mean values for treatments N_1, N_2 and N_3 were displaced to the right on the abscissa by an amount equivalent to the displacement necessary for check. This process was successively repeated for all eight sets of data. With respect to the last two sets, since there was a marked decrease in slope for these curves, only the two previous fittings in each case were used for locating the position of the check points. The actual yields of corn grain and the calculated fertilizer nitrogen equivalents, as just mentioned, are presented in Table 32.

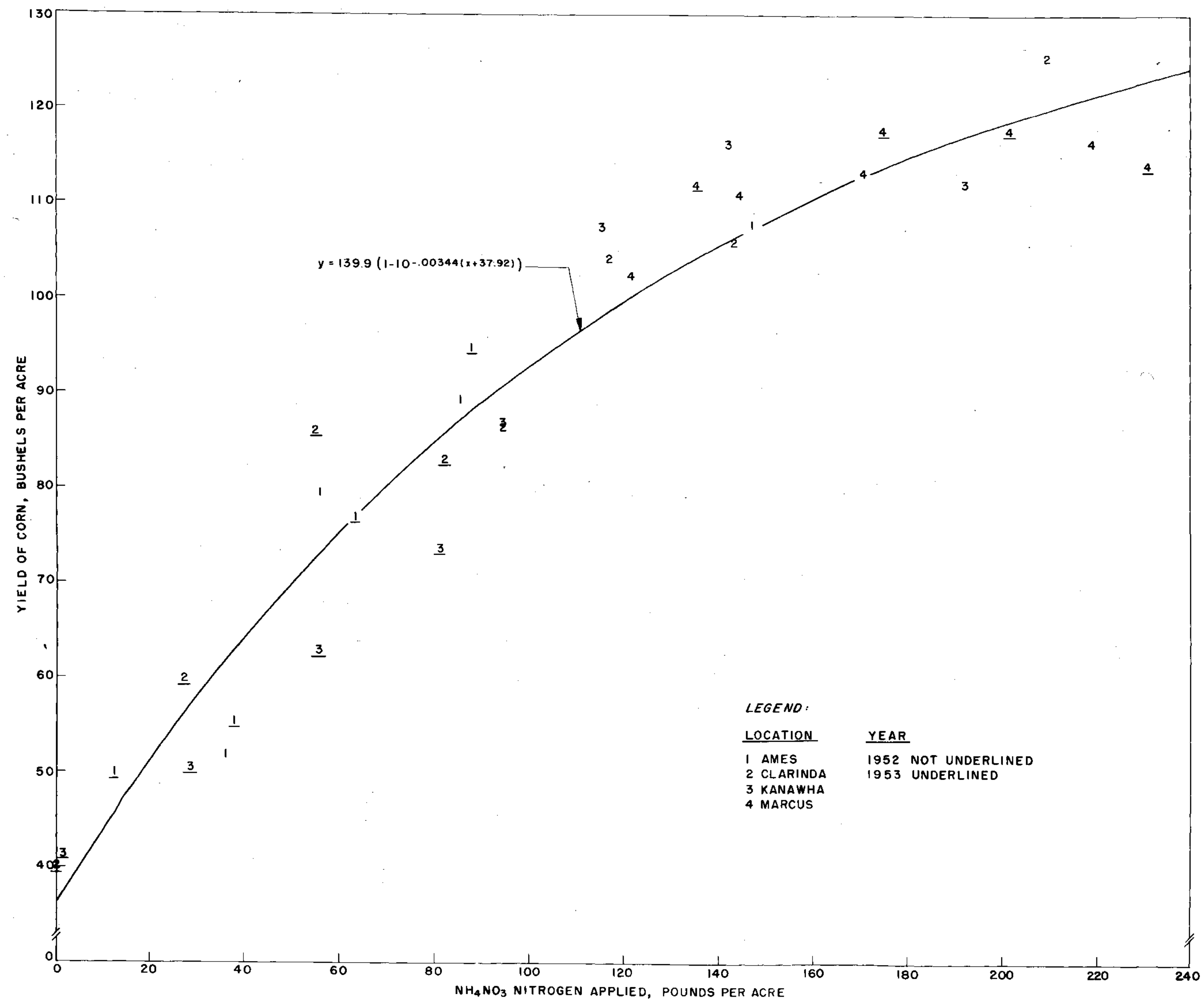
The tabulated pairs of data are graphically depicted in Fig. 15. These data were fitted to a logarithmic curve of the general form $Y = M - A R^x$ by the method of least squares presented and illustrated

Table 32. Fertilizer nitrogen equivalents and associated corn yields used as standards in the evaluation of green manures

Location	Year	Check		N_1		N_2		N_3	
		Fertilizer nitrogen[1] equivalent (lbs./A)	Corn yield (bu./A)	Fertilizer nitrogen equivalent (lbs./A)	Corn yield (bu./A)	Fertilizer nitrogen equivalent (lbs./A)	Corn yield (bu./A)	Fertilizer nitrogen equivalent (lbs./A)	Corn yield (bu./A)
Clarinda	1953	0	40.3	27.4	59.9	54.9	86.0	82.6	83.0
Kanawha	1953	1.7	41.4	28.7	50.6	55.7	63.0	81.4	73.7
Ames	1953	12.3	50.1	38.0	55.5	63.7	76.9	94.9	87.9
Ames	1952	36.2	51.8	56.0	79.5	85.6	89.4	147.2	107.9
Clarinda	1952	94.4	86.5	117.2	104.2	143.5	106.0	209.5	125.6
Kanawha	1952	94.4	86.8	115.8	107.6	142.5	116.2	192.4	112.1
Marcus	1952	122.0	102.3	144.6	110.9	170.6	113.3	219.2	116.6
Marcus	1953	135.6	112.0	174.9	117.8	201.8	117.7	231.3	114.2

[1]Fertilizer nitrogen equivalents were determined by least squares fitting of individual yield response curves when lowest check yield ($y = 40.3$ bu./A) was considered at $x = 0$.

Fig. 15. Corn yield responses to ammonium nitrate or calculated ammonium nitrate equivalents when lowest check yield ($y = 40.3$ bu./A) was plotted at $x = 0$



YIELD OF CORN, BUSHELS PER ACRE
NH4NO3 NITROGEN APPLIED, POUNDS PER ACRE
y = 139.9 (1-10-.00344(x+37.92))
LEGEND:
LOCATION
1 AMES
2 CLARINDA
3 KANAWHA
4 MARCUS
YEAR
1952 NOT UNDERLINED
1953 UNDERLINED

by Eid et al. (24). In this equation, Y is the yield associated with x units of nitrogen in terms of added ammonium nitrate, A is the asymptote to the curve as x approaches infinity and R is the ratio of a decreasing geometric series the terms of which are the respective increments in yield due to successive increments in x (79). This logarithmic curve, which can also be written in the form $\log (A - y) = \log A - c(x+b)$, has oftentimes been referred to as the Mitscherlich curve, and has been used extensively in soil fertility investigations. The fitted curve obtained here was $\log (139.9 - y) = \log 139.9 - .00344\ (x+37.92)$.

It should be emphasized that this particular curve was used only as a matter of convenience and as a tool. It was assumed that the constants A and c were the same for all locations and years, and that the b value applicable to the data associated with the lowest check yield was also a reasonable estimate for other soil types. Whether these assumptions were met or not is open to question. However, a number of facts lead to the belief that there was some justification in using this subjective approach.

In the first place, the difficulties previously mentioned were overcome. The calculated response curve to ammonium nitrate encompassed the whole range of legume nitrogen applications. A continuous curve with one overall slope was available for comparing green manure effects on corn yields and only a few points were found above the fertilizer response curve (Fig. 16). In the second place, the small scatter evident in Fig. 15, as well as the fact that such an empirical curve could be constructed, seems further justification for the approach utilized.

Thirdly, although no attempts were made to interpret the calculated values for the three constants in terms of soil characteristics, it is of interest to note that Hanway and Dumenil (35), reporting on a large number of Iowa field experiments on corn response to nitrogen fertilizer, obtained values of .003525 and 104 for c and A, respectively. Even though the A value of 139.9 obtained in the current investigation was considerably larger than the one obtained by these authors, the present study was conducted at higher fertility and particularly higher population levels than the experiments reported by Hanway and Dumenil. The two c values are, for all practical purposes, identical. It might be pointed out, at this juncture, that a similar procedure to the one used here was utilized by Mitchell and Chandler (52) in analyzing data on nitrogen nutrition of deciduous trees.

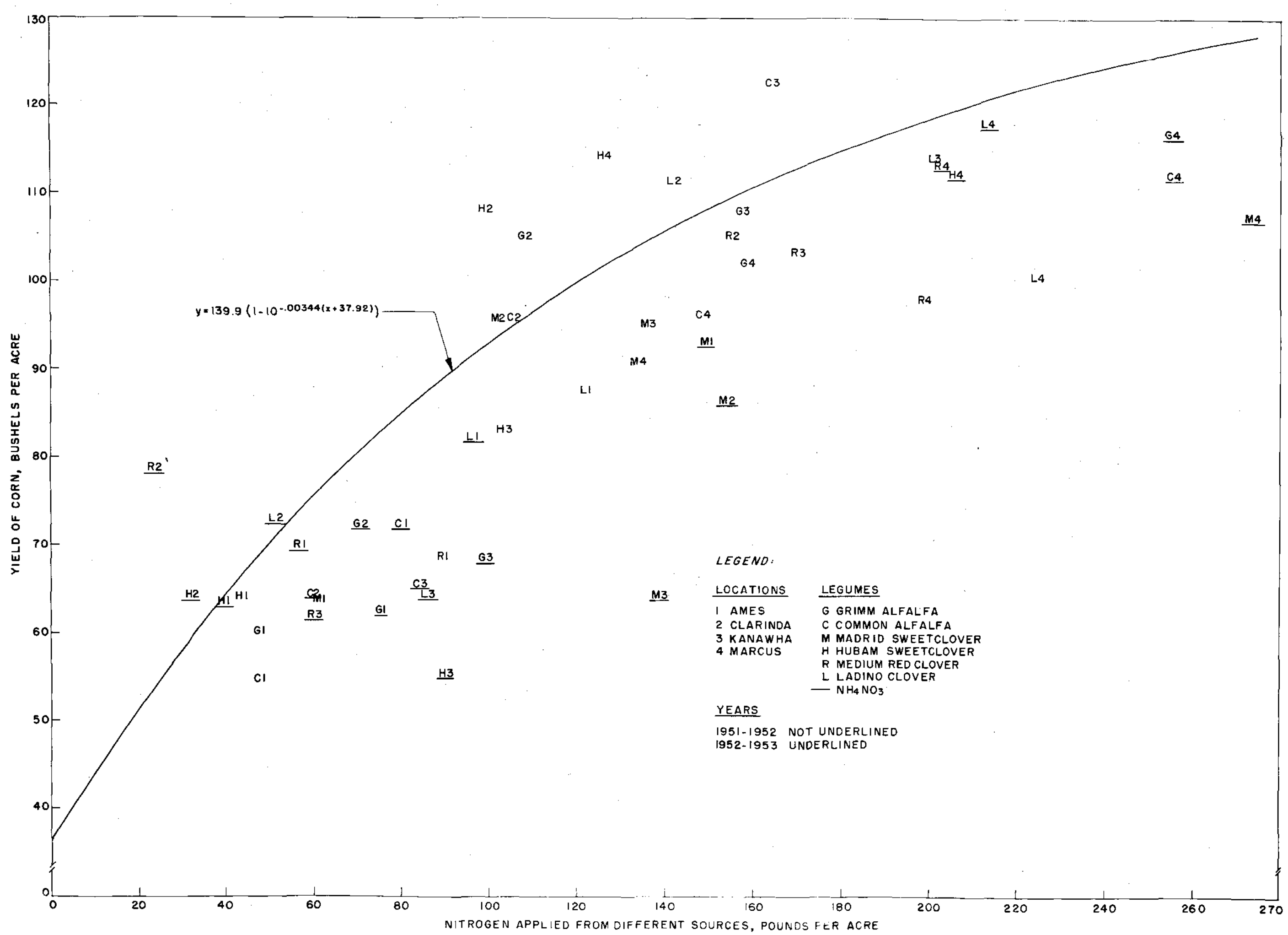
Fourthly, nitrate production in the laboratory, as measured by the method proposed by Stanford and Hanway (80) on soil samples obtained in the spring of 1951 on the areas where corn was grown in 1952, further corroborated the relative nitrogen supplying power of the different soils. Three analyses were carried out on each sample, one for a one-week incubation period, and the other two each for a two-week incubation. When the nitrate production from soil at Marcus was considered to be 100 (30 p.p.m. and 73 p.p.m. nitrate release in one and two weeks, respectively), relative nitrate productions of 91, 56 and 46 were obtained for soils at Kanawha, Clarinda and Ames, respectively. These values are arrayed in generally the same order as the nitrogen fertilizer equivalent values for check yields presented in Table 32, particularly with regard to the 1952 data.

The ease of construction of the curve, the small scatter obtained and the corroborative evidence of nitrate production in the laboratory, all point to the fact that this calculated response curve has great merit and can be used with confidence in evaluating effects of green manures on corn in terms of response of the crop to ammonium nitrate.

Corn yields in relation to nitrogen contained in the previous green manure crops, as well as the calculated corn yield response curve to ammonium nitrate nitrogen, are presented graphically in Fig. 16. Actual corn yield was utilized for the ordinate. With respect to the abscissa, the total nitrogen content of each legume at a particular location in one season was added to the fertilizer nitrogen equivalents for the appropriate check soil (Table 32, third column).

Examination of Fig. 16 revealed that the great majority of the corn yields following legume green manure treatments were below and reasonably close to the ammonium nitrate curve. This fact indicated that, in general, legume nitrogen did not result in as high a corn yield as did ammonium nitrate nitrogen over a wide range of application rates under diverse environmental conditions. Ten legume treatment corn yields were still encountered above the inorganic nitrogen response curve. Of these ten points, four were very close to the calculated curve. Reasons for deviations of the other six are obscure, but four of these were from Clarinda experiments. It is conceivable that Marshall silt loam may have responded to green manure treatment in a manner different from

Fig. 16. Relationship between green manures and inorganic fertilizer as sources of nitrogen for corn



YIELD OF CORN, BUSHELS PER ACRE
NITROGEN APPLIED FROM DIFFERENT SOURCES, POUNDS PER ACRE
0 20 40 60 80 100 120 140 160 180 200 220 240 260 270
0 40 50 60 70 80 90 100 110 120 130
y = 139.9 (1-10^-.00344(x+37.92))
LEGEND:
LOCATIONS
1 AMES
2 CLARINDA
3 KANAWHA
4 MARCUS
LEGUMES
G GRIMM ALFALFA
C COMMON ALFALFA
M MADRID SWEETCLOVER
H HUBAM SWEETCLOVER
R MEDIUM RED CLOVER
L LADINO CLOVER
— NH4NO3
YEARS
1951-1952 NOT UNDERLINED
1952-1953 UNDERLINED

the other soil types studied, or that legume effects here could not be totally ascribed to nitrogen content alone. On the other hand, these deviations may have been due to experimental errors associated with all procedures and methods.

It is possible, from the relationships expressed in Fig. 16, to attach a mathematical meaning to the comparison between leguminous and inorganic nitrogen. Considering each individual corn response to legume green manure, the actual mean corn yield obtained from a green manure treatment at a location in one year was substituted in the calculated equation for corn response to ammonium nitrate nitrogen. The resulting equation was then solved for x. This value was an expression of the equivalent pounds of inorganic nitrogen required over all experiments for production of the same corn yield as was obtained from the green manure treatment. The ratio of pounds ammonium nitrate nitrogen calculated in this way to pounds nitrogen in the legume, after subtraction of the correction factor used previously (Table 32, third column), was called "legume nitrogen efficiency". These calculated efficiencies, which are gross estimates of the relative value of a unit weight of legume nitrogen as compared to the same amount of ammonium nitrate nitrogen, are presented in Table 33.

Analysis of variance of the legume nitrogen efficiencies indicated no significant differences among legumes; however, the locations by years interaction was significant at the five percent level of probability. There was a tendency for efficiencies to be larger for the alfalfas and sweetclovers grown in 1951 and evaluated with corn in 1952,

Table 33. Mean efficiencies of legume nitrogen of six green manures in relation to corn response to ammonium nitrate fertilizer

Leguminous green manure	Nitrogen efficiency (percent)
Grimm alfalfa	77.4
Southern common alfalfa	77.0
Madrid sweetclover	64.3
Hubam sweetclover	98.8[1]
Medium red clover	73.4
Ladino clover	84.6

[1] As previously stated, yields of Hubam sweetclover were underestimated due to loss of leaves prior to harvest. This would result in a higher efficiency value.

than for those same legumes studied in the 1952-1953 series. This observation follows the conclusion arrived at by Löhnis (47, among others) in 1926. He stated that small amounts of green manures gave, as a rule, higher percentage returns than large quantities of organic materials added to soil. The picture is further obscured by the fact that the stage of growth and the ensuing nitrogen content of different green manures may vary at the time of their incorporation in the soil. It also has been determined that the rate of addition of organic materials is not the sole factor in operation with respect to nitrogen availability of green manures. There appears to be a stimulatory effect resulting from the addition of leguminous (10, 34, 47) or of other energy material to a soil (12). Furthermore, the mere growing of a leguminous crop on a soil may result in high nitrification rates (27, 46), even though little time has elapsed to allow decomposition of legumes to have taken place. Thus, a leguminous crop may contribute a certain amount of nitrogen in addition to the actual quantity contained in its tissues.

These facts help explain, to a certain extent, the variations obtained in the legume nitrogen efficiencies calculated in the current investigation. The value obtained for Madrid sweetclover (64.3 percent) was approximately ten percent lower than those obtained for the two alfalfas and medium red clover. Since the growth and nitrogen content of Madrid sweetclover were high in 1952, the large quantity of material plowed under was not as efficient as it would have been with a smaller amount (47). It also has been pointed out that some materials do not decompose as rapidly when added at high rates than when applied at lower rates (12). The data obtained in the corn-1952, oats-1953 experiment at Ames (Fig. 14) substantiated that observation. In summary, it can be concluded that legume nitrogen, as evaluated by the methods of this investigation, was between 65 and 85 percent as efficient as an equal amount of inorganic nitrogen in increasing corn yields. Nevertheless, it should be recalled that the greatest single influence in determining corn yields after green manure treatments was the total amount of dry matter and nitrogen that was plowed under.

One of the main difficulties in this investigation was the fact that there was no control over the amount of growth of each legume. Whatever stand was obtained, and whatever dry matter or nitrogen yield was produced, had to be used for green manure. Supplementary studies at Ames indicated that freshly-cut alfalfa, applied at increasing rates, resulted in higher corn yields than similar amounts of freshly-cut red clover. Future field investigations on leguminous green manures should consider the possibility of measuring succeeding crop yields resulting from applications of varying amounts of legume tops and/or roots.

In addition to corn yield, leaf nitrogen content was used as a criterion to differentiate between treatments. When each experiment was considered separately, there was very good agreement between yield and leaf nitrogen percentage. Since date of sampling at each experimental site could not be adequately controlled, no attempt was made to establish relationships over all experiments between nitrogen treatments and corn leaf nitrogen percentages. Nevertheless, leaf nitrogen was of great value in corroborating yield evidence. Thomas (81) recognized that foliar diagnosis is a comparative method for differentiating between treatments, and is not an absolute method. He further stated that "foliar diagnosis considered independently of all other field data and of all other foliar diagnosis has no physiological significance".

In general, somewhat the same level of nitrogen in the leaf as has been found by others (1, 7, 82, 83) was found to be the critical percentage (2.8 to 3.0 percent nitrogen in the leaf). Some exceptions were found in cases where the samples were obtained at an earlier date than the time when corn plants were in silk and shedding pollen. Tyner (82) found that for each increase of 0.1 percent nitrogen in the leaf, there was a yield increase of approximately four and a half bushels; on the other hand, Bennett et al. (7) obtained only a 3.2 bushel yield increase for each 0.1 percent increase in leaf nitrogen. In this investigation, a range of from four to six bushels yield increase was obtained for each 0.1 percent increase in leaf nitrogen content. This relationship varied with location, year, treatment and yield level of check. This variation, larger than that found by others, can again be explained largely on the basis of earlier sampling than is recommended.

Up to this point, the presentation and discussion of results has been limited to an attempt to relate the effect of green manures on corn yield to the effect of ammonium nitrate on corn yield. In this connection, the recovery of leguminous nitrogen, as measured by corn yield response and in comparison with ammonium nitrate effects on corn yield, has been estimated. Going one step further, it would be of great interest and value to estimate the recovery by corn of added nitrogen of either organic or inorganic form. The investigation reported here was not conducted with this specific goal in mind, but fragmentary evidence in the literature may provide some indications as to the existing relationships.

Jones and Huston (40) found in 1914 that 10,000 plants of corn contained 111 pounds of nitrogen, of which 79 pounds were in the ears. Illinois data (102) indicated that corn yields of 50 to 80 bushels per acre were accompanied by stover yields of one to one and a half tons per acre containing usually between 0.5 and 0.8 percent nitrogen. Ohlrogge et al. (63) stated that two pounds of applied nitrogen per acre were needed by the crop for each one bushel yield increase. They further mentioned that approximately one half of the applied nitrogen was recovered in grain and stover, although the range varied from 35 to 60 percent recovery according to environmental conditions. Smith (72) arrived at a similar conclusion in Missouri; his data indicated that two pounds nitrogen per acre were required for each bushel of corn, and he concluded that a 100-bushel corn crop needed 160 to 215 pounds of nitrogen per acre. On the other hand, Viets and Domingo (88) found that only 1.34 pounds nitrogen per acre resulted in one bushel increase of corn at application rates of 90 pounds of nitrogen per acre; under their conditions, half of the applied nitrogen was recovered in the grain.

In Illinois, Kurtz et al. (44) found that corn yields of about 50, 90 and 115 bushels per acre resulted in grain plus stover nitrogen yields of about 50, 135 and 180 pounds of nitrogen per acre, respectively. In an investigation of the effect of phosphorus and nitrogen on yield and composition of corn, Gray (33) found that, in general, one third the total nitrogen was contained in stover and the remaining two thirds in the grain. In an experiment in Illinois in 1951, he found that corn yields of 75 to almost 110 bushels per acre were accompanied by stover yields of 3900 to 4900 pounds per acre. The total nitrogen uptake varied with corn yield from 59 to 106 pounds per acre. Yield increases over check of 15, 22 and 33 bushels resulted in nitrogen uptake increases over check of 20, 36 and 47 pounds per acre, respectively. Jordan et al. (41) reported that, with plant populations of 12,000 stalks per acre, the recovery of nitrogen from applications of 60 and 120 pounds inorganic nitrogen per acre were 88.8 and 73.0 percent of check, respectively. The check treatment contained 29.5 poundsnitrogen per acre (grain, stalks, leaves, husks and cobs), and the two other treatments (60 and 120 pounds applied nitrogen) contained 82.8 and 117.1 pounds nitrogen per acre, respectively.

From this short review of the nitrogen uptake by corn at different yield levels, it would seem that roughly one and a third to two pounds of nitrogen are required for each bushel of corn. The source of inorganic nitrogen involved generally is of little significance (59), provided the nitrogen is available to the corn crop prior to pollination. As the yield per acre increases, and also as the nitrogen application increases, the efficiency of the fertilizer decreases. In general, between 50 and 75 percent of the applied nitrogen is recovered by the aerial portions of the corn crop. No critical data on nitrogen yield of corn roots was encountered in the literature. However, most data indicate that yields of from 40 or 50 to 110 or 120 bushels per acre are accompanied by total nitrogen uptakes of from about 50 to 180 or more pounds of nitrogen per acre.

On the basis of these data, and in view of the previously established relationship between legume and ammonium nitrate nitrogen, the calculated range of leguminous nitrogen recovery by corn would be between 35 and 65 percent of amount applied. Whether the remaining leguminous nitrogen is of value to succeeding crops or not is open to question; even if such were the case, it is entirely possible that field experiments, however carefully conducted, might not measure existing differences. At this juncture, it should be recalled that the growing of a legume on a particular field, followed by complete removal of hay or seed crops, still has resulted in increased yields of succeeding crops. The reasons for this phenomenon are still far from clear. However, many investigators have ascribed to legumes beneficial effects other than nitrogen contribution.

In this investigation, emphasis has been placed upon the nitrogenous effect of legumes, and all comparisons were made on that basis with respect to influence on succeeding crop. If other factors were operative, they were confounded with nitrogen effects. Many writers have maintained that one of the effects of legumes is the improvement of soil structure. Evidence has accumulated that the growing of a leguminous crop or the addition of organic residues do increase soil aggregation (13, 29, 55, 86, among others), water percolation (48) and other soil characteristics. However, critical attempts to relate these effects on soil structure to increases in yields of succeeding crops have not met with success wherever soil physical conditions were not so poor as to entirely prohibit normal agricultural practices.

In 1890, Muntz (54) wrote that "even in view of the advantageous results which are obtained from the use of green manures, there is value in using them only in specific economic conditions, since one harvest needs be sacrificed in order to feed the succeeding crop" (translated from the French by the present writer). This statement still holds true today. Not only the contribution of leguminous green manures to increasing yield of succeeding crops needs be taken into consideration, but also the economics of such practices in present-day agriculture.

Estimates of seed costs of different legumes, based on current prices, are presented in Table 34. On the basis of these estimates, it would cost an average of 3.05 dollars per acre to establish a leguminous crop. In view of the nitrogen yields reported in this study for various legumes, the cost per pound of nitrogen would amount to about 2.6, 2.8, 3.7 and 7.6 cents for Madrid sweetclover, ladino clover, common alfalfa and medium red clover, respectively. These costs can be compared to the price of 15 cents per pound of nitrogen in ammonium nitrate fertilizer.

The results of this investigation pointed out that only a certain portion of the total nitrogen in the legumes was equivalent to ammonium nitrate in terms of corn production. In other words, there is some legume nitrogen left over after the corn crop that follows the green manure, even if in many cases it seems that this residual nitrogen cannot be measured with present-day methodology. Evidence obtained in 1951 indicated that seeding of legumes in oats did not decrease yield of the companion crop. Therefore, comparison of the cost of leguminous nitrogen with the cost of ammonium nitrate nitrogen for the production of equivalent amounts of corn yield increases would be conservative.

Table 34. Estimates of seeding costs for leguminous green manures

Legume	Seeding rate (lbs./A)	Cost of seed ($/A)
Southern common alfalfa	10	2.80
Medium red clover	8	3.20
Ladino clover	4	2.40
Yellow sweetclover	10	3.80[1]

[1]Includes cost of insecticide and its application at $2.00 per acre.

Assuming that only two thirds of the plowed under legume nitrogen is effective the following year in increasing corn yields where nitrogen is limiting grain production, one pound of nitrogen in the form of biennial sweetclover, ladino clover, common alfalfa or medium red clover would cost approximately 4.0, 4.4, 5.6 and 11.4 cents, respectively. These values again should be compared to the cost of 15 cents per pound of ammonium nitrate nitrogen.

From an economic standpoint, the inclusion in a rotation of a relatively large acreage of oats is not profitable in Iowa, since corn is capable of yielding a much larger quantity of grain than oats under present-day conditions. Therefore, differences in yield between corn and oats should be charged (at least, in part) to the cost per pound of nitrogen from legumes. Recently, investigations in Ohio (37, 38), Iowa (69)and other places have pointed out a new and promising attack upon this problem. It has been possible to establish stands of leguminous plants in corn rows spaced more widely than is currently the practice. Although, up to the present, slight yield reductions have resulted from wide-row corn spacing, the lower corn yields still have been much superior in grain production to normal oat yields. The possibility of establishing leguminous green manures in wide-row corn companion crops deserves investigation, as well as the evaluation of the total nitrogen contribution to be expected from legumes grown under those conditions.

In conclusion, the growing of leguminous green manures to be plowed under at the end of the seeding year compares favorably with other methods of supplying nitrogen to succeeding crops in Iowa. Since disease, insect pests, and climatic factors can so readily decimate stands and reduce growth and development of the legumes, it seems advisable to recommend a mixture of green manures rather than the sole use of one species. The cheapest and most effective mixture in terms of total nitrogen contribution and versatility with respect to environmental conditions would consist of four species (Table 35).

This seeding mixture would, at current prices, cost approximately 3.15 dollars per acre, and could be expected to result in the production of at least 50 to 100 or more pounds of nitrogen costing less than seven cents per pound. Yellow-flowered sweetclover should, in this

Table 35. Recommended legumes and seeding rates for green manure purposes in Iowa

Legume	Seeding rate (lbs./A)
Madrid sweetclover	3
Southern common alfalfa	3
Medium red clover	3
Ladino clover	.5 to 1

mixture, produce the greatest growth and total nitrogen in years when sweetclover weevil injury is slight. When insect attacks reduce stands of sweetclover, alfalfa would provide good growth under dry conditions, whereas medium red clover would predominate under moist and cooler conditions. The excellent results obtained in this investigation with ladino clover warrant its inclusion in this mixture, particularly in regions of adequate rainfall such as the eastern half of the state of Iowa.

VI. SUMMARY AND CONCLUSIONS

An investigation was carried out at four locations in Iowa during the period 1951-1953. The major objective was to evaluate different legumes when used as green manures in the fall of the seeding year. Exploratory experiments with a large number of legumes with varying degrees of adaptation to Iowa were carried out for the purpose of estimating their potential value as green manures. Major emphasis was placed upon the comparison of six legumes: Madrid sweetclover, Hubam sweetclover, Grimm alfalfa, southern-grown common alfalfa, medium red clover and ladino clover. The dry matter yields and nitrogen contents of both roots and tops of these six legumes were measured. Effects of these legumes on a succeeding corn crop were evaluated in comparison with inorganic nitrogen fertilizer. Additional studies were conducted to compare availability to corn of nitrogen from freshly-cut and other organic materials.

Stands, and hence yields, of legumes were affected by disease and sweetclover weevil in one year, while in the second year good stands of all seedings were obtained. Total dry matter yields (tops plus roots) of ladino and medium red clover in 1951 were about one and a half tons per acre, while alfalfas and sweetclovers yielded one half ton or less per acre. In 1952, Madrid sweetclover yielded two and a half tons dry matter per acre, alfalfas about two tons, ladino clover a ton and a half and red clover between one and one and a half tons per acre. Hubam sweetclover yields were low in both years as a result of the annual growth habit of the species and because sampling was carried out after leaf loss had occurred. Grimm and the strain of southern-grown common alfalfa were not significantly different in either dry matter yields or nitrogen contents. Exploratory experiments indicated that some strains of southern alfalfas vary in their yielding ability. Mammoth red clover yield was half that of medium red clover.

Nitrogen percentage of legume tops or roots did not vary significantly among species. Nitrogen yields, however, varied widely among legumes because of the wide variations in dry matter yields. When good stands were obtained, Madrid sweetclover yielded 135 to 150 pounds of nitrogen per acre, alfalfas yielded between 60 and 120 pounds, ladino clover between 50 and 110 and medium red clover between 35 and 80 pounds of nitrogen per acre in tops and roots. The variations observed within legumes were due to the effects of both location and season.

A correlation of .976 was obtained between total dry matter yield and total nitrogen yield for all legumes at all locations for both years. The correlation for all legumes between dry matter yield of tops (cut at the crown) and total nitrogen yield was .936. The latter relationship between top growth and total nitrogen yield lends confidence to the possible evaluation of legumes in terms of top yields alone.

Madrid sweetclover root yields were nearly equal to the top yields. Alfalfa top-root ratios were slightly higher than those for biennial sweetclover. Red clover top-root ratios were about 3.5 to 4.5, whereas those for ladino clover were slightly higher. The top-root ratios for nitrogen yields were usually higher than corresponding ratios for dry matter yields, indicating the somewhat higher nitrogen contents of tops.

Mowing in midsummer, as indicated by experience at one location and in one year, drastically reduced fall top and root yields of the sweetclovers. This close clipping resulted in increased yields of the other legumes.

Exploratory studies of a number of other legumes revealed that some species other than those included in the major study, such as Korean lespedeza, crimson clover and hairy vetch, deserved further investigation as to their value as green manure crops in Iowa.

Corn responded to both inorganic nitrogen applications and leguminous green manure treatments at three of the four locations in both years. The location where no yield response was obtained in either year had check yields of over 102 bushels of corn per acre. The corn yields following green manure treatments were, in general, proportional to the total nitrogen content of the legumes, and hence to their total growth. At some locations, no direct relationship between ammonium nitrate and legume treatments could be established with respect to efficiency of nitrogen source. However, when all corn yield responses were considered simultaneously, it was concluded that leguminous nitrogen was between 65 and 85 percent as efficient as ammonium nitrate in increasing corn yield.

Nitrogen percentage of corn leaves within each location and season was directly related to corn yield. Cob yields closely followed those of shelled corn. Only minor differences occurred among treatments in shelling percentage.

Additional studies were conducted with different rates of application of freshly-cut and other organic materials applied in early spring onto a single corn field. Freshly-cut alfalfa tops were more efficient in increasing corn yields than equivalent rates of application of freshly-cut red clover tops of slightly higher nitrogen content. Alfalfa applications were less efficient than ammonium nitrate treatments. Low-nitrogen materials such as soybean straw resulted in no corn yield increases over check. Residual nitrogen effects from these treatments, measured the succeeding year with an indicator crop of oats, were non-significant.

Availability of green manure nitrogen, as determined from the comparative yield responses to legume green manures and total nitrogen immobilization in corn, was estimated to range between one third and two thirds of that contained in the legume.

A brief consideration of the economic aspects of legume green manure utilization as compared to inorganic fertilizer as a source of nitrogen for corn in Iowa emphasized the relatively low cost of leguminous nitrogen.

A seeding mixture consisting of yellow-flowered biennial sweet-clover, southern common alfalfa, medium red clover and ladino clover, was suggested for green manure purposes in Iowa.

VII. LITERATURE CITED

1. Andharia, R. M., Stanford, G. and Schaller, F. W. Nitrogen status of Marshall silt loam as influenced by different crop rotations. Soil Sci. Soc. Amer. Proc. (1952) 17: 247-251. 1953.

2. Arny, A. C. and McGinnis, F. W. The relative value of the annual white, the biennial white, and the biennial yellow sweet clovers. Jour. Amer. Soc. Agron. 16: 384-396. 1924.

3. _______ and Thatcher, R. W. The effect of different methods of inoculation on the yield and protein content of alfalfa and sweet clover. Jour. Amer. Soc. Agron. 7:172-185. 1915.

4. Atkins, Ozell A. and Young, W. C. The partridge pea, Chamaecrista fasciculata, a promising plant for soil conservation. Jour. Amer. Soc. Agron. 33:471-472. 1941.

5. Badger, C. J. and Snider, H. J. The composition of the spring growth of sweet clover as influenced by previous fall treatment. Jour. Amer. Soc. Agron. 25:105-108. 1933.

6. Baker, Donald G., Rost, C. O. and Kramer, H. W. Influence of fertilizers on four legumes when grown as green manures. Minn. Agr. Exp. Sta. Tech. Bul. 204. 1952.

7. Bennett, William F., Stanford, George and Dumenil, Lloyd. Nitrogen, phosphorus, and potassium contents of the corn leaf and grain as related to nitrogen fertilization and yield. Soil Sci. Soc. Amer. Proc. (1952) 17:252-258. 1953.

8. Borgeson, Carl. Methods of detasseling and yield of hybrid seed corn. Jour. Amer. Soc. Agron. 35:919-922. 1943.

9. Bozovaisky, L. S. Some factors which influence the growth of Dalea alopecuroides, Wild. Unpublished M.S. Thesis. Iowa State College Library. 1936.

10. Broadbent, F. E. Nitrogen release and carbon loss from soil organic matter during decomposition of added plant residues. Soil Sci. Soc. Amer. Proc. (1947) 12:246-249. 1948.

11. _______ The soil organic fraction. Advances in Agron. 5:153-183. 1953.

12. _______ and Norman, A. G. Some factors affecting the availability of the organic nitrogen in soil. A preliminary report. Soil Sci. Soc. Amer. Proc. (1946) 11:264-267. 1947.

13. Browning, G. M. and Milam, F. M. Rate of application of organic matter in relation to soil aggregation. Soil Sci. Soc. Amer. Proc. (1940) 6:96-97. 1941.

14. Burnett, Kenneth Hensel. Experiments on fall clipping of sweet clover. Unpublished M. S. Thesis. Iowa State College Library. 1938.

15. Butijn, J. Proeven met groenbem est ingsgewassen in de fruitteelt in 1950. (Experiments with green manure crops in fruit-growing in 1950). Mededelingen Directie van den Tuinbouw 14:341-356. 1951.

16. Carlson, F. A. The effect of soil structure on the character of alfalfa root-systems. Jour. Amer. Soc. Agron. 17:336-345. 1925.

17. Davis, J. F. The effect of sweetclover green manure on crop yields on the heavy soils in Michigan. Soil Sci. Soc. Amer. Proc. (1942) 7:290-293. 1943.

18. _______ A method for estimating the weight of roots of green manure crops. Jour. Amer. Soc. Agron. 37:661-662. 1945.

19. _______ and Turk, L. M. The effect of fertilizers and the age of plants on the quality of alfalfa and sweetclover for green manure. Soil Sci. Soc. Amer. Proc. (1943) 8:298-303. 1944.

20. Doughty, J. L. The rate of decomposition of plant roots. Sci. Agr. 21:429-432. 1941.

21. Duncan, Elwin Raymond. Interrelations of plant populations, fertility levels and hybrids in corn production. Unpublished Ph.D. Thesis. Iowa State College Library. 1954.

22. Dungan, George H. Relation of blade injury to the yielding ability of corn plants. Jour. Amer. Soc. Agron. 22:164-170. 1930.

23. Dunham, R. S. Effect of method of sowing on the yield and root and top development of sweet clover in the Red River Valley. Jour. Agr. Res. 47:979-995. 1933.

24. Eid, M. T., Black, C. A. Kempthorne, O. and Zoellner, J. A. Significance of soil organic phosphorus to plant growth. Iowa Agr. Exp. Sta. Res. Bul. 406. 1954.

25. Ensminger, L. E. and Pearson, R. W. Soil nitrogen. Advances in Agron. 2:81-111. 1950.

26. Erdman, Lewis W. and Means, Ura Mae. Use of total yield for predicting nitrogen content of inoculated legumes grown in sand cultures. Soil Sci. 73:231-235. 1952.

27. Fitts, J. W., Bartholomew, W. V. and Heidel, H. Correlation between nitrifiable nitrogen and yield response of corn to nitrogen fertilization on Iowa soils. Soil Sci. Soc. Amer. Proc. (1952) 17:119-122. 1953.

28. Fribourg, H. A. A rapid method for washing roots. Agron. Jour. 45:334-335. 1953.

29. Gilmour, C. M., Allen, O. N., and Truog, E. Soil aggregation as influenced by the growth of mold species, kind of soil, and organic matter. Soil Sci. Soc. Amer. Proc. (1948) 13:292-296. 1949.

30. Goedewaagen, M. A. J. and Schuurman, J. J. Wortelproductie op bouw-en grasland als bron van organische stof in de grond. (Root production in arable and grassland as a source of organic matter). Landbouwk. Tijdschr. 62:469-482. 1950.

31. ________ and ________ Root production by agricultural crops on arable land and on grassland as a source of organic matter in the soil. Trans. Fourth Internatl. Cong. Soil Sci. 2:28-31. 1950.

32. Goodding, T. H., Duley F. L. and Russel, J. C. Partridge pea in a stubble-mulch system. Soil Sci. Soc. Amer. Proc. (1948) 13:558-560. 1949.

33. Gray, Carl. Relation of soil and fertilizer nitrogen to yield and composition of corn. Unpublished Ph.D. Thesis. University of Illinois Library. 1953.

34. Hallam, M. J. and Bartholomew, W. V. Influence of rate of plant residue addition in accelerating the decomposition of soil organic matter. Soil Sci. Soc. Amer. Proc. (1952) 17:365-368. 1953.

35. Hanway, John and Dumenil, Lloyd. Predicting nitrogen fertilizer needs of Iowa soils: III. Use of nitrate production together with other information as a basis for making nitrogen fertilizer recommendations for corn in Iowa. Soil Sci. Soc. Amer. Proc. (1953) 18:---- 1954. (In press)

36. Hawk, Virgil B. The effect of clipping on the yield and nitrogen content of sweetclover. Unpublished M.S. Thesis. State College of Washington Library. 1938.

37. Haynes, J. L. and Stringfield, G. H. Green manure between the corn rows. Ohio Farmer 211:5, 30. March 21, 1953.

38. _______ and _______ Wider corn rows. Ohio Farm and Home Res. 38:20, 34-35. March-April 1953.

39. Hervey, R. J., Kapp, L. C., Johnston, J. R. and Smith, J. C. Use of sweetclover for deep-placement of phosphorus. Soil Sci. Soc. Amer. Proc. (1950) 15:258-262. 1951.

40. Jones, W. J., Jr. and Huston, H. A. Composition of maize at various stages of its growth. Ind. Agr. Exp. Sta. Bul. 175:596-623. 1914.

41. Jordan, Howard J., Laird, Kermit D. and Ferguson, D. D. Growth rates and nutrient uptake by corn in a fertilizer-spacing experiment. Agron. Jour. 42:261-268. 1950.

42. Keuls, M. The use of the "Studentized Range" in connection with an analysis of variance. Euphytica 1:112-122. 1952.

43. Kohnke, Helmut and Miles, S. R. Rates and patterns of seeding corn on higher-fertility land. Agron. Jour. 43:488-493. 1951.

44. Kurtz, Touby, Melsted, S. W. and Bray, Roger H. Yield and nitrogen composition of two single-cross corn hybrids when grown in alternate rows. Agron. Jour. 41:474-476. 1949.

45. Lamba, P. S., Ahlgren, H. L. and Muckenhirn, R. J. Root growth of alfalfa, medium red clover, brome and timothy under various soil conditions. Jour. Amer. Soc. Agron. 41:451-458. 1949.

46. Landrau, Pablo, Jr. Influence of cropping and cultural practices on the seasonal trends in nitrification rates of soils used for growing corn in Nebraska. Puerto Rico Agr. Exp. Sta. Tech. Paper 10. 1953.

47. Löhnis, F. Nitrogen availability of green manures. Soil Sci. 22: 253-290. 1926.

48. McCalla, T. M. The influence of microorganisms and some organic substances on water percolation through a layer of Peorian loess. Soil Sci. Soc. Amer. Proc. (1945) 10:175-179. 1946.

49. _______ and Russel, J. C. Nitrate production as affected by sweetclover residues left on the surface of the soil. Jour. Amer. Soc. Agron. 40:411-421. 1948.

50. Martin, Thomas L. Decomposition studies of alfalfa and sweet clover roots and straw. Soil Sci. 24:309-316. 1927.

51. Maynard, L. A. The decomposition of sweetclover as a green manure under greenhouse conditions. N. Y. Agr. Exp. Sta. (Cornell) Bul. 394. 1917.

52. Mitchell, Harold L. and Chandler, Robert F. Jr. The nitrogen nutrition and growth of certain deciduous trees of northeastern United States. Black Rock Forest Bul. 11. 1939.

53. Muhr, Gilbert R. and Rost, C. O. The effect of population and fertility on yields of sweet corn and field corn. Agron. Jour. 43:315-319. 1951.

54. Muntz, A. Du rôle des engrais verts comme fumure azotée. Acad. Sci. (Paris) Compt. rend. 110:972-975. 1890.

55. Myers, H. E. and Myers, H. G. Soil aggregation as a factor in yields following alfalfa. Amer. Soc. Agr. Jour. 36:965-969. 1944.

56. Newlin, Owen. Water loss from grain and associated plant parts of corn after physiologic maturity. Unpublished M.S. Thesis. Iowa State College Library. 1953.

57. Newman, D. The distribution of range in samples from a normal population, expressed in terms of an independent estimate of standard deviation. Biometrika 31:20-30. 1939.

58. Norman, A. G. Recent advances in soil microbiology. Soil Sci. Soc. Amer. Proc. (1946) 11:9-15. 1947.

59. North Carolina Agricultural Experiment Station. Sources of nitrogen in crop production. North Carol. Agr. Exp. Sta. Tech. Bul. 96. 1952.

60. Obenshain, S. S. and Gish, P. T. The effect of green-manure crops on certain properties of Berks silt loam. Va. Agr. Exp. Sta. Tech. Bul. 73. 1941.

61. O'Grady, Lawrence J. The effect of alfalfa and sugar beet residues on following crops. La Revue d' Oka 22:66-81, 95-126, 127-156. 1948.

62. Ohio Agricultural Experiment Station. Handbook of Ohio Experiments in Agronomy. Ohio Agr. Exp. Sta. Book Series B-1. 1951.

63. Ohlrogge, A. J., Krantz, B. A. and Scarseth, G. D. The recovery of plowed-under ammonium sulfate by corn. Soil Sci. Soc. Amer. Proc. (1943) 8:196-200. 1944.

64. Pieters, A. J. Green manuring: A review of the American experiment station literature. Jour. Amer. Soc. Agron. 9:62-82, 109-126, 162-190. 1917.

65. _______ Green manuring: Principles and practice. John Wiley & Sons, Inc. New York. 1927.

66. Piper, C. S. Soil and plant analysis. Interscience Publishers. New York. pp. 368. 1950.

67. Rogers, T. H. and Sturkie, D. G. Effect of fertilizers and method of their application on nodulation, growth, and nitrogen content of hairy vetch. Jour. Amer. Soc. Agron. 31:141-148. 1939.

68. Scales, F. M. and Harrison, A. P. Boric acid modification of the Kjeldahl method for crop and soil analysis. Jour. Ind. and Eng. Chem. 12:350-352. 1920.

69. Schaller, F. W. Corn as a nurse crop. Iowa Farm Science 8 (10): 26-27. 1954.

70. Schmid, A. R., Crim, R. F. and Rost, C. O. Good crop rotation boosts corn yields. Minn. Farm and Home Sci. 10 (1):4-5. 1952.

71. Smith, Dale and Graber, L. F. Effect of top growth removal in root and vegetative development of biennial sweetclover. Jour. Amer. Soc. Agron. 40:818-831. 1948.

72. Smith, G. E. Soil fertility and corn production. Mo. Agr. Exp. Sta. Bul. 583. 1952.

73. Smith, Henry W. and Vandecaveye, S. C. Productivity and organic matter levels of Palouse silt loam as affected by organic residues and nitrogen fertilizers. Soil Sci. 62:283-291. 1946.

74. Smith, T. Jackson. Responses of biennial sweet clover to moisture, temperature, and length of day. Jour. Amer. Soc. Agron. 34: 865-876. 1942.

75. Snider, H. J. Chemical composition of hay and forage crops. Ill. Agr. Exp. Sta. Bul. 518. 1946.

76. _______ and Hein, M. A. The nitrogen and dry matter content of sweet clover tops and roots at various stages of growth. Jour. Amer. Soc. Agron. 18:273-280. 1926.

77. _______ and _______ The influence of soil treatment upon the composition of sweet clover. Jour. Amer. Soc. Agron. 26:740-745. 1934.

78. Spaulding, Major F. and Eisenmenger, Walter S. Factors influencing the rate of decomposition of different types of plant tissue in soil, and the effect of the products on plant growth. Soil Sci. 45:427-446. 1938.

79. Spillman, W. J. Use of the exponential yield curve in fertilizer experiments. U.S.D.A. Tech. Bul. 348. 1933.

80. Stanford, George and Hanway, John. Predicting nitrogen fertilizer needs of Iowa soils: I. A simplified technique for determining relative nitrification rates. Soil Sci. Soc. Amer. Proc. (1953) 18: (In press). 1954.

81. Thomas, Walter. Foliar diagnosis: principles and practice. Plant Phys. 12:571-600. 1937.

82. Tyner, Edward H. The relation of corn yields to leaf nitrogen, phosphorus and potassium content. Soil Sci. Soc. Amer. Proc. (1946) 11:317-323. 1947.

83. _______ and Webb, John R. The relation of corn yields to nutrient balance as revealed by leaf analysis. Jour. Amer. Soc. Agron. 38:173-185. 1946.

84. Upchurch, R. P. and Lovvorn, R. L. Gross morphological root habits of alfalfa in North Carolina. Agron. Jour. 43:493-498. 1951.

85. U. S. Department of Agriculture. Agricultural Statistics 1953. Washington, D. C. 1953.

86. van Bavel, C. H. M. and Schaller, F. W. Soil aggregation, organic matter and yields in a long-time experiment as affected by crop management. Soil Sci. Soc. Amer. Proc. (1950) 15:399-404. 1951.

87. van de Goor, G. A. W. The value of some leguminous plants as green manures in comparison with Crotalaria juncea. Netherlands Jour. of Agr. Sci. 2:37-43. 1954.

88. Viets, Frank G., Jr. and Domingo, Clifford E. Yields and nitrogen content of corn hybrids as affected by nitrogen supply. Soil Sci. Soc. Amer. Proc. (1948) 13:303-306. 1949.

89. Ward, Henry S. Jr. Reactions of adapted legumes and grasses on the structural condition of eroded Lindley-Weller soils in southeastern Iowa. Ecol. Monog. 19:145-171. 1949.

90. Whiting, A. L. Some important factors controlling the rate of nitrification of organic materials. Jour. Amer. Soc. Agron. 18:854-876. 1926.

91. ________ and Richmond, Thomas E. Sweetclover for nitrate production. Ill. Agr. Exp. Sta. Bul. 233. 1921.

92. ________ and ________ The composition of biennial white sweet clover as related to soil enrichment. Soil Sci. 22:83-95. 1926.

93. ________ and ________ The relative rates of nitrification of different parts of sweet clover plants. Soil Sci. 24:31-38. 1927.

94. ________ and ________ Experiments in handling sweet clover with reference to the accumulation and conservation of nitrates in the soil. Ill. Agr. Exp. Sta. Bul. 285. 1927.

95. Whyte, R. O., Nilsson-Leissner, G. and Trumble, H. C. Legumes in agriculture. Food and Agr. Org. of the United Nations. Agr. Studies No. 21. 1953.

96. Wilkins, F. S. and Collins, E. V. Effect of time, depth and method of plowing upon yield and eradication of biennial sweetclover. Iowa Agr. Exp. Sta. Res. Bul. 162. 1933.

97. ________, Hughes, H. D., Brown, P. E. and Smith, F. B. Hubam clover, biennial white sweet clover, medium red clover and dalea, as green manures. Iowa Agr. Exp. Sta. Report on Agr. Res. 1930/31: 70. 1931.

98. Willard, C. J. An experimental study of sweet clover. Ohio Agr. Exp. Sta. Bul. 405. 1927.

99. ________ The correlation between stand and yield of alfalfa and sweetclover. Jour. Agr. Res. 43:461-464. 1931.

100. ________, Jones, Earl, Thatcher, L. E., Haynes, J. L. and Dodd, D. R. Choosing and sowing meadow and pasture seedings. Ohio Agr. Exp. Sta. Bul. 261. 1953.

101. Wilson, Perry W. The biochemistry of symbiotic nitrogen fixation. The University of Wisconsin Press. Madison, Wis. 1940.

102. Wimer, D. C. Composition of mature corn stover as affected by variety, soil type and fertilizer treatment. Ill. Agr. Exp. Sta. Bul. 437. 1937.

VIII. ACKNOWLEDGMENTS

The author wishes to express his sincere thanks and deep appreciation to Dr. I. J. Johnson and Dr. W. V. Bartholomew for their untiring guidance and constructive criticism in directing this study and preparing this manuscript.

Acknowledgments and thanks are due to Dr. R. R. Kalton, Dr. W. E. Loomis, Dr. J. E. Sass and Dr. G. Stanford for serving on the author's graduate committee, and to the several staff members of the Agronomy Department at Iowa State College for their able and willing assistance.

IX. VITA

Henry August Fribourg, son of Jean and Yvonne Oury Fribourg, was born in Paris, France, on the tenth of March, 1929. He received his elementary schooling in Paris, and was admitted to the Lycée Rollin in June 1939. He attended the Lycées in Fontainebleau, Nîmes and Algiers from October 1939 to November 1941. He then pursued his secondary education in Havana, Cuba, and completed it at Haaren High School, in New York City.

He entered the University of Wisconsin in September 1945, and received his Bachelor of Science in Agriculture with honors in January 1949. While at that institution, between 1947 and 1949, he was Teaching Assistant in the Department of French and Italian.

In February 1949, he was granted a fellowship established by the Cooperative Grange League Federation for forage crop research at Cornell University, and received his Master of Science degree at that institution in June 1951, with a major in Field Crops and a minor in Plant Breeding.

In the spring of 1951, he enrolled in the Graduate School at Iowa State College as a candidate for the degree of Doctor of Philosophy, with a joint major in Crop Production and Soil Management and minors in Plant Physiology and Crop Breeding. In June 1952, he was awarded an assistantship established by an agency of the Federal Government for investigation of the effects of growth regulators on crop plants.

On June 18, 1951, one of his fondest desires was fulfilled when he became a citizen of the United States of America. In the summer of 1952, he was employed as Interpreter at the Sixth International Grassland Congress, and was Chief Interpreter for the Second Inter-American Meeting on Livestock Production held in Brazil in December 1952.